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SST Technology
Follow-On Program – Phase I

COMPATIBILITY OF SST MATERIALS WITH TITANIUM ALLOYS; VOLUME II, MANUFACTURING—AID MATERIALS

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DEPARTMENT OF TRANSPORTATION • UNITED STATES OF AMERICA

D6-60208-2
July, 1972

FINAL REPORT
Task 1

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Prepared for

FEDERAL AVIATION ADMINISTRATION
Supersonic Transport Office
800 Independence Avenue, S.W.
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Disclaimer

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16. Abstract

This document presents data on the compatibility of titanium alloys Ti-8Al-1Mo-1V and Ti-6Al-4V with manufacturing aid materials, which might have contacted titanium during fabrication of the U.S.A. supersonic transport. Testing proceedures are described and results are tabulated.

Test methods included use of a simple U-bend specimen, use of Heimerl-Braski self-stressed specimens, application of the Allison bend test for detection of surface embrittlement, emittance measurements, and analyses for the hydrogen and oxygen content of exposed titanium, and for the chlorine content of manufacturing aid materials. For each material-specimen-test parameter combination a rating of "compatible" or "incompatible" is assigned.

Sections are included on the nature of the stress-corrosion cracking produced by the action of hot salt and of methanol on the alloys. Photomicrographs of fracture surfaces are included.

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PREFACE

This is one of a series of final reports on Titanium Materials Technology submitted in fulfillment of Task 1-A of Department of Transportation contract DOT-FA-SS-71-12, dated 30 June 1971. The report was prepared by the Materials Technology organization of The Boeing Company, Commercial Airplane Group, Seattle, Washington.

This document is volume II of a two-volume series. Volume I covers flyaway materials, volume II covers manufacturing aid materials.

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1.0 INTRODUCTION

This document records experience acquired by The Boeing Company concerning the compatibility of titanium alloys with aircraft manufacturing materials. The experience was gained during the Supersonic Transport (SST) program. Some of the data had been reported previously in an internally released Boeing Document (ref. 1).

This document is Volume 2 of a two volume series and covers manufacturing-aid materials, which are described as those substances such as drilling fluids, cleaners, etchants, or other materials which contact titanium alloys during component fabrication. In addition, a few substances (food stuffs, chemicals, etc.) which might accidentally contact titanium during shop handling were included. Volume 1 of this document (ref. 2) covers flyaway materials, such as coatings, sealants, oils, fuels, etc. which could contact the titanium alloys during normal aircraft operation.

Several of the tests used to determine the data recorded in this volume are described in detail in Volume 1, which also contains a short background discussion of the problem of stress corrosion cracking of titanium.

A rating of compatible (A) or incompatible (X) has been assigned for each material-alloy-exposure condition tested. An A rating does not constitute a recommendation for selecting a manufacturing aid material; obviously this requires an engineering judgement based upon all the material properties and the requirements of the proposed use. An X rating does not rule out using a material in contact with titanium in applications where it would encounter environmental stresses significantly lower than those used in the test.

2.0 BACKGROUND

Limited attention was paid to the stress corrosion behavior of titanium or its alloys prior to 1955, since it was not believed that titanium was prone to the problems that were involved with other alloy systems (ref. 3). In late 1955 it was discovered that a salty fingerprint was the source of a stress-corrosion failure of a Ti-6Al-4V specimen during a 700°F creep test. This stress-corrosion effect of hot salt on titanium alloys was confirmed by other investigators (refs. 4 and 5).

In early 1966 B.F. Brown of the Naval Research Laboratory reported (ref. 6) that a titanium alloy (8 Al-1Mo-1V) was susceptible to stress-corrosion at room temperature. The Apollo fuel tank failure of December 1966 (ref. 7) during pressure testing using methyl alcohol served to intensity the study of environmental effects on titanium and titanium alloys.

Hydrogen embrittlement is another source of titanium alloy degradation. It can result from improper wet processing (typically nitric-hydrofluoric acid solutions) and from gaseous water during heat treating (ref. 8), and can result in seriously reduced fatigue resistance of parts. A related problem is titanium oxidation at high temperatures, producing a thick brittle oxide coating, which must be removed by a pickling process.

During manufacture of airplane parts, titanium will contact a wide variety of substances, collectively referred to as manufacturing aid materials. Each of these represents a potential source of stress-corrosion cracking and hydrogen embrittlement. For this reason Boeing began to accumulate test data on the compatibility of manufacturing aid materials with titanium alloys early in the SST program. The present document summarizes this test program.

Deterioration may occur not only during the manufacturing process involving a manufacturing aid, but also at a later time during a subsequent high temperature operation (e.g., stress-relief) if residual material is present. For this reason data on stress-corrosion is included at temperatures far above actual use values.

The data presented herein was acquired over a five year period. During this time an evolution of test methods occurred, and emphasis shifted from Ti-8Al-1Mo-1V to Ti-6Al-4V, the structural alloy eventually selected for SST use. Some data were also obtained on other titanium alloys, including Ti-4Al-3Mo-1V, Ti-5A-2.5 Sn, and CP titanium. Simultaneously, manufacturing methods were evolving. Some of the earlier data may not be as informative as some of that obtained later in the program, and direct comparison of materials tested early and late may not be possible. Nevertheless, the data is sufficient to guide the intelligent selection of manufacturing aid materials in order to avoid incompatibility problems.

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3.0 TEST METHODS

Brief descriptions are given in this section of the tests used in obtaining the compatibility data listed in section 5, including methods for detecting the occurance of embrittlement, corrosion, or stress corrosion, and the chemical analytical techniques used to identify test materials and to measure exposure produced changes in titanium alloy composition. Detailed laboratory directions for several of these are given in volume I.

Early in the program the modified Allison bend test was the primary method used to detect attack on titanium. This test can indicate the formation of a brittle surface layer due to either hydrogen embrittlement or oxidation. Since the specimen is exposed unstressed it will not detect susceptibility to stress corrosion cracking (SCC). A regular sequence of tests was employed including:

- Exposure of specimen coupons to the test material at the pertinent time-temperature conditions.
- Microscopic examination of the specimen surface for corrosion or etching.
- Allison bend testing to detect formation of a brittle surface layer.
- Gas analysis of broken Allison bend specimens to detect increased hydrogen content.

During the latter portion of the test program, when the importance of stress-corrosion cracking as a titanium degradation mechanism was more fully appreciated, emphasis shifted to the use of the U-bend test as the primary method of detecting incompatibility. This test, described in detail in Vol. 1, although not quantitative in nature, is inexpensive, relatively rapid, sensitive, and is admirably suited for a screening program in which large numbers of materials are to be tested.

In studying heat treat coatings the emittanc of the surface following exposure was measured to detect the presence of an oxide coat and to obtain some indication of its thickness. An additional thickness measurement wa en made by removing various thicknesses by chemical milling, according to BAC 5842, until the emittance value of the milled specimen had dropped back to that typical of the bare metal.

3.1 SPECIMEN PREPARATION AND EXPOSURE

The majority of the data in this report deals with the SST structural titanium alloy containing 6 percent aluminum and 4 percent vanadium (Ti-6-4). Data on two other alloys is included: Ti-8-1-1, containing 8 percent aluminum, 1 percent molybdenum and 1 percent vanadium; and Ti-4-3-1, containing 4 percent aluminum, 3 percent molybdenum, and 1 percent vanadium. A few tests on pure titanium and on titanium containing 5 percent aluminum and 2.5 percent tin are also included. Test specimens were fabricated from flat stock 0.040 to 0.050-inches thick. Specimens were cleaned using a standard Boeing process (BAC 5753,

Method 2), which is described in volume 1 of this report (ref. 2). Unless otherwise indicated, specimen sizes depended upon the particular test to be run, as described below.

3.1.1 Continuous Exposure Test (Flat Sheet Exposure)

For [illegible]uous ex[illegible]ure tests candidate materials (lubricants, tapes, etc.) were brushed on otherw[illegible]ied to [illegible]5 x 6.00 inch sheets, and exposed at varying temperatures depending upon the [illegible] m[illegible]al being evaluated and the usage conditions being simulated.

3.1.2 Intermittent Exposure Test (Drip Corrosion)

An intermittent exposure test was originally designed to evaluate the effects of hot Skydrol on titanium and other metals. This test procedure was also used for the evaluation of the effects of machining lubricants and other fluid materials on titanium.

A 1.75 x 6-inch specimen of titanium was suspended at an angle of 20-30° in a heated pot. A burette containing the candidate fluid was positioned and adjusted so that a steady drip of material impinged on the top section of the specimen. Vacuum sealing tape was used along the edges of the specimen to maintain the flow of fluid the entire length without going over the edges and coating the under surface. Time at temperature varied depending upon the effects noted in the preliminary hours but generally testing was overnight or 16 to 17 hours.

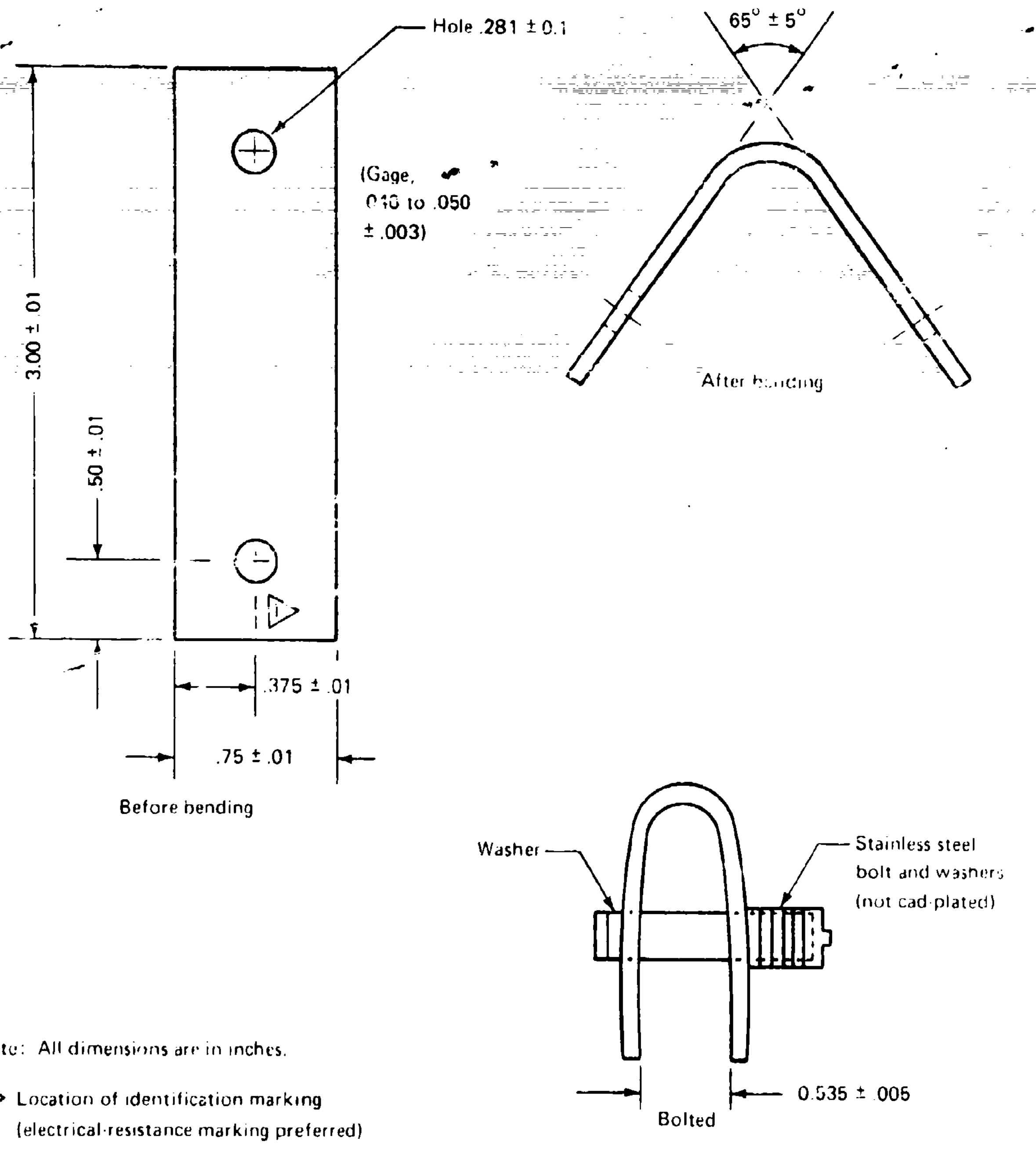
Depending upon the size of the pot, a series of specimens may be used with a separate burette for each specimen. A control specimen was exposed at the same temperature but without contact with candidate material.

3.2 HEIMERL-BRASKI SELF-STRESSED SPECIMENS

This method for detecting stress corrosion employs two end-joined titanium coupons stressed to some predetermined level during material exposure by insertion of a cylindrical wedge. Specimen dimensions, specimen fabrication, application of test materials, environmental exposure, and compression testing following exposure as used in this program are described in detail in volume 1 of this document (ref. 2), together with stress-level calculations for this specimen configuration. The original description of the method by Heimerl and Braski is given in references 5 and 9.

3.3 U-BEND AND RESIN KETTLE TEST

The U-bend test is described in detail in volume 1 of this document (ref. 2). The single U-bend (S-U) specimen is a coupon bent into the form of the letter U, with dimensions such that the metal is stressed near to or above its yield point. Specimen configuration is shown in figure 1. A test material is applied to the convex side of the bend, and the specimen is exposed to the test environment. The metal surface is then cleaned and examined for stress cracking and corrosion. A rating of A or X is assigned to the alloy-material-environment combination by applying specified criteria, as listed in table 1.



Note: All dimensions are in inches.

1 Location of identification marking (electrical-resistance marking preferred)

FIGURE 1.–U-BEND SPECIMEN

Modifications of this test described in volume 1 are the double U-bend test (D-U) in which the test material is trapped between two nested U-bends to simulate faying surface exposure, and the indented U-bend (I-U) in which small indentations along the center line of the bend are used to increase test sensitivity.

3.3.1 U-bend Test (Ambient)

This test was first used to evaluate the stress-corrosion effects of methanol on titanium but was subsequently extended to include other liquid materials. The test is simple a U-bend specimen is immersed in the material which is at room temperature. Exposure times to failure have been noted from a few minutes to 75 hours depending upon the titanium alloy, surface conditions, and the liquid environment.

The standard test employed specimens chemically cleaned per Method 2, BAC 5753. Variations in surface condition were found to be important and, therefore, care was exercised in noting exact surface history. All specimens were used un-notched, unless otherwise noted.

The importance of the stress level in determining susceptibility to corrosion is shown in figure 2. Small differences in the included angle between the legs of the specimen do not affect the time to fracture appreciably. This is because the apex of the bend is at or above the yield stress of the alloy for all small angles. However as the included angles rises above about 15° the applied stress decreases rapidly, and the susceptibility to corrosion, as shown by time to rupture, increases correspondingly. In considering this data it must be recognized that methanol, even at room temperature, represents an extremely severe environment for titanium alloys.

3.3.2 U-bend Test (Elevated Temperature)

The cleaned and stressed U-Bend specimens were dipped into or coated with candidate material. The specimens were drained with the open end up so that material would concentrate on the area of maximum stress. After overnight ambient drying the specimens were placed in a pre-heated, electrically fired oven typically for four hours at 1000°F. After exposure the specimens were descaled per BAC 5753, Method 2. Immersion in Turco 4316 Scale Conditioner or equivalent for 30 minutes followed by a four-minute immersion in the HNO_3-HF-pickle removed all heat-treat scale. The descaled specimens were examined microscopically for evidences of surface etch or stress corrosion cracking. Specimens were sectioned and micrographs taken as required. All specimens were used un-notched, unless otherwise noted.

3.3.3 Resin Kettle Test

The term "Resin Kettle Test" was applied in this program to a test in which a specimen of the U-bend type was exposed to vapors evolved from a test fluid. Although the exposure vessel was not sealed, in order to allow venting, the openings were small, and a vapor atmosphere was maintained around the specimen by gravity effects for the test duration. This allowed detection of stress-corrosion produced by decomposition products of the vapor on the titanium alloy surface.

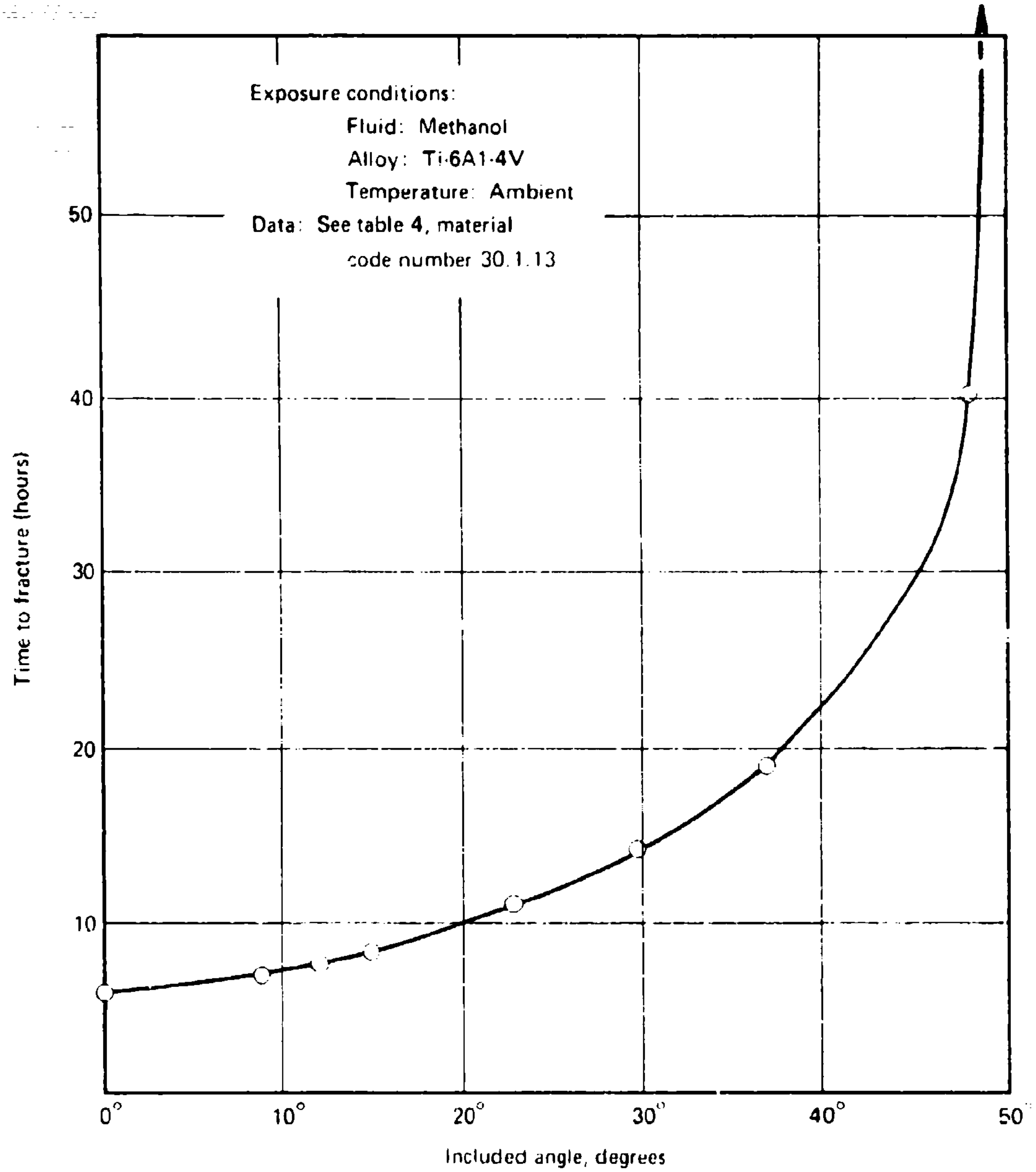


FIGURE 2. -TIME TO FRACTURE OF U-BEND SPECIMENS RELATED TO THE INCLUDED ANGLE BETWEEN SPECIMEN SIDES

The reaction chamber used for testing was a resin kettle of 4000 ml capacity. A typical test was as follows:

- The glass resin-kettle apparatus was chemically cleaned and baked at 350°F for 3 to 6 hours.

- Two Ti 6Al-4V and Ti 8Al-1Mo 1V alloy U-bend specimens (alkaline and HNO_3-HF pickle cleaned before restraint) were placed in the bottom of the kettle with the stressed surface upward.

- The lid of the kettle was secured with two openings left open for fume exhaust.

- The material in question, when a liquid, was poured into the kettle through an opening in the lid, whereupon the whole assembly was placed in a preheated explosion-proof, vented oven. A volume of 35-38 ml was used.

- Time at temperature varied with desired simulated exposure, but was generally only two hours at 850°F. (Time was found not to be a significant factor.)

- After exposure, the specimens were inspected for cracks. When required, wet penetrant inspection and microscopic examination were used.

3.4 MODIFIED ALLISON BEND TEST

The Allison bend test was originally developed to study the toughness and crack propagation properties of steel alloys (ref. 10). Work at Boeing had shown that results of this test were strongly affected by the surface condition of the test coupons, as well as by the bulk properties of the alloy. Because of this observation, this test was chosen to study surface embrittlement of titanium alloys produced by exposure to manufacturing aid materials.

In the test thin gage specimens are bent to fracture over a small mandrel, using a fixture as shown in figure 3. The load deflection curve is recorded during this process. Figure 4 illustrates load-deflection curves typical of a non-embrittled control specimen and of a specimen exhibiting severe surface embrittlement. The two curves are approximately the same from the origin to point A (at the maximum stress) where the convex surface begins to yield. Curve A-E traces the continued yielding of the control coupon until it fractures, allowing the stress to go to zero along E-D. If the alloy is sufficiently tough, fracture may occur in steps leading to curves such as the dashed line E-D′. The area A-B-D-E-A (or A-B-D′-E-A) is measured using a planimeter. Expressed in inch-pounds it is called the bend-energy of the control.

In an embrittled specimen small surface cracks develop at the yield point A. These act as stress risers, so that the curve drops off to the axis along A-C (or A-C′) with fracture occurring at a lesser head travel distance. The bend energy (area of A-B-C-A or A-B-C′-A) is measured and compared to that of the control. A decrease of 15-percent or greater in the bend energy, relative to the control is considered significant evidence of surface embrittlement. This method of data interpretation differs from that originally suggested by Hanik in which the differences between the maximum stress and the stress at which fracture is initiated (i.e. stress at A stress at E for the control) are compared for various specimens.

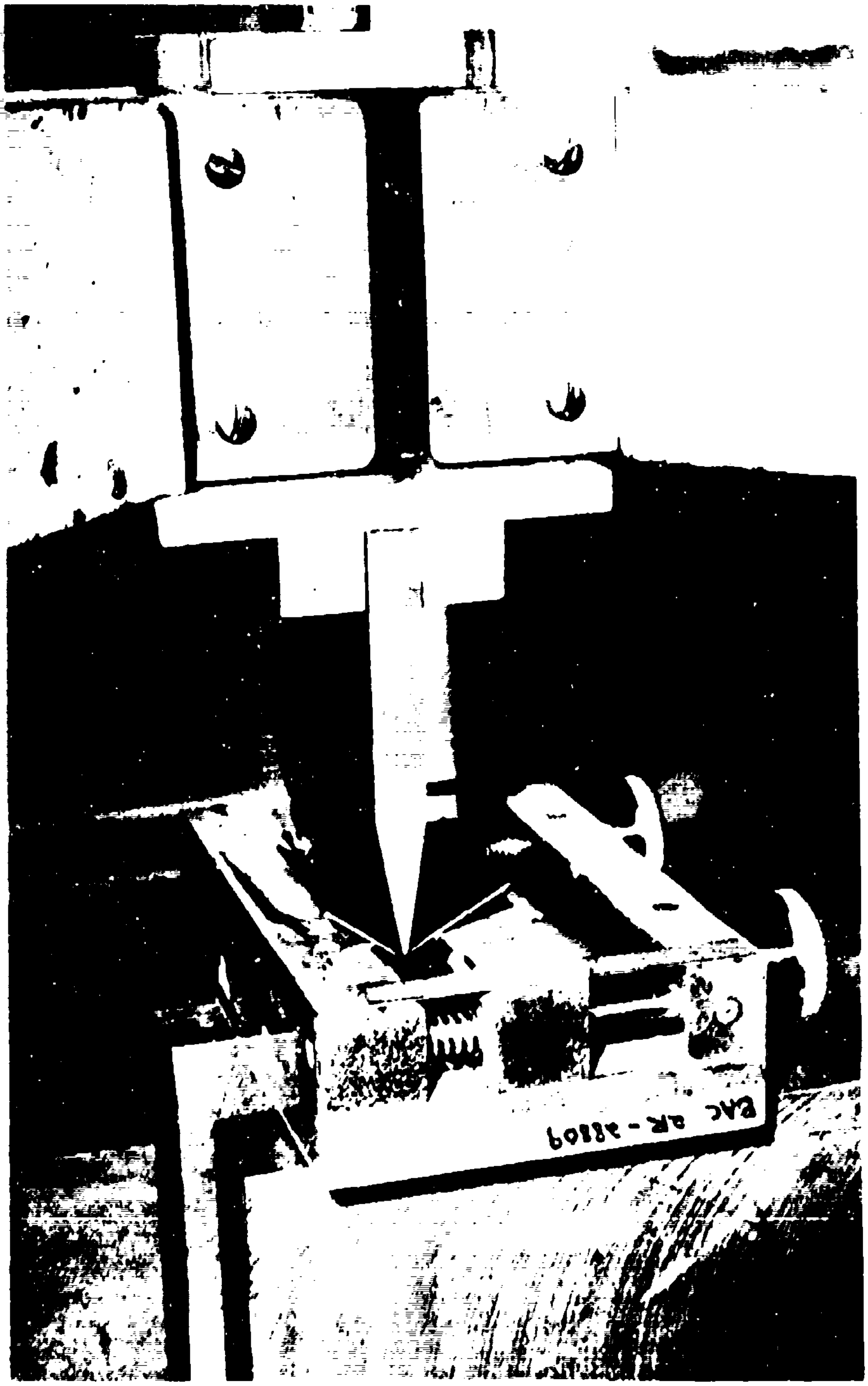


FIGURE 3. -ALLISON BEND TEST SET UP

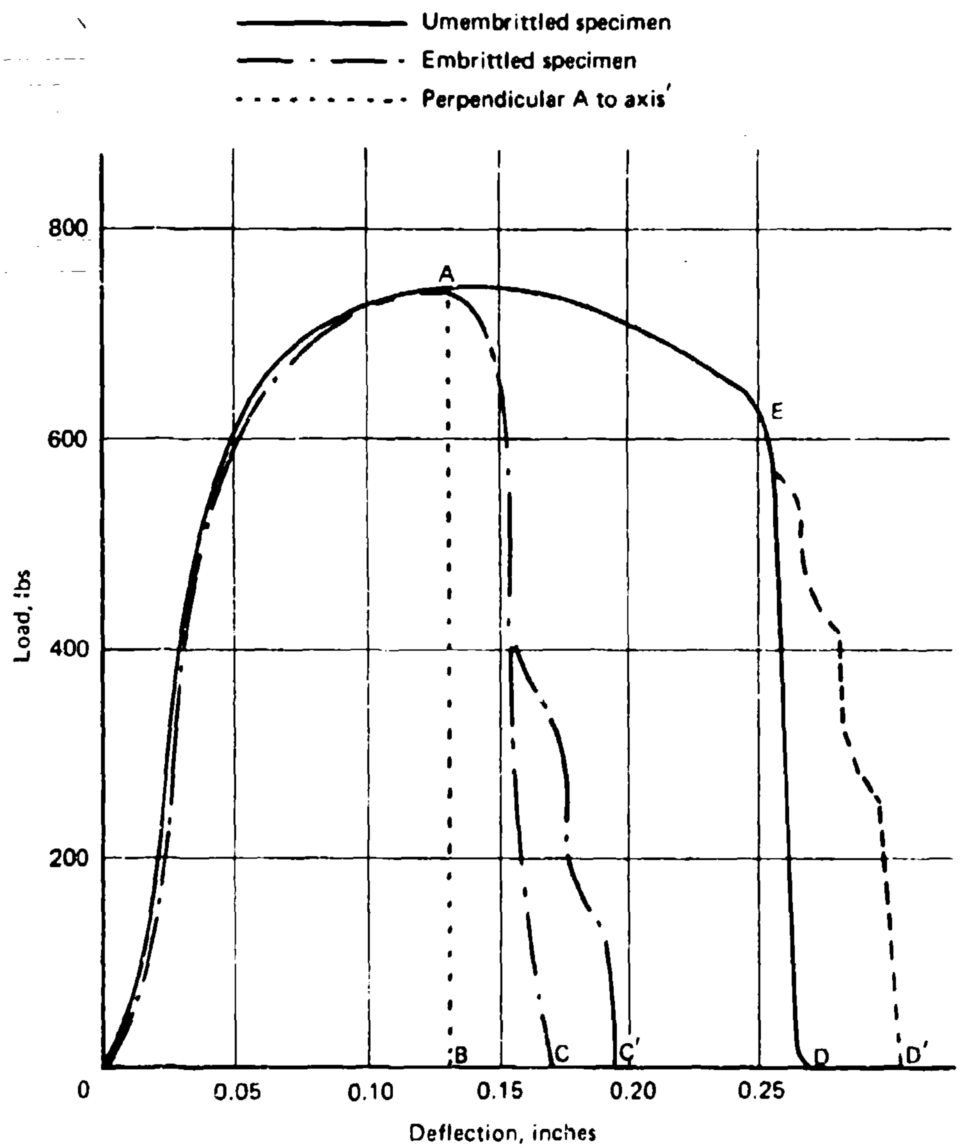


FIGURE 4.--LOAD DEFLECTION CURVE, ALLISON BEND TEST

A standard specimen is fabricated from 0.040 or 0.050-inch sheet stock, and is 1.75 x 2.00 inches, with the 2-inch dimension along the rolling direction. Specimens are cleaned according to BAC 5753, Method 2, and exposed as described in 3.1.1 above. Fracture is induced in the long or rolling direction, using a 0.034-inch radius mandrel. The channel width of the jig is set at 14-times the specimen thickness, and the head travel speed is 0.25 inches per minute.

3.5 EMITTANCE TEST

This test is based on the correlation between the degree of oxidation of a titanium surface, and the surface emittance. It was used to evaluate the ability of heat treat protective coatings to protect titanium surfaces from oxidation. Emittance is defined as the ratio of energy radiated per unit time from a unit surface area from a body to the energy radiated from a perfect black body at the same temperature.

The emittance of materials is a surface phenomenon. A metal surface in its natural state exhibits a certain emittance that is characteristic of that particular metal. The same metal covered with another layer, such as an oxide film or a synthetic coating, possesses an emittance property which is generally significantly different from that of the natural metal surface. Very thin films are very nearly transparent to radiant energy and their emittance properties are greatly influenced by the metal substrate. When the coating on a metal surface is sufficiently thick and opaque, the emittance of the composite is that of the coating itself.

The following typical data illustrates how emittance measurements can furnish information about the state of titanium surfaces.

Total Emittance

Titanium Alloy	Values
Ti 6Al-4V	
Theoretical (clean & smooth)	0.143
Chemically Cleaned	0.15
As-Received	0.19
400°F Oxidized	0.21
Anodized Titanium	
Gold	0.14
Blue Gray	0.17
Gray Black	0.32
Gray	0.38

In studying heat treat coatings the emittance of the surface following exposure was measured to detect the presence of an oxide coating, and to obtain some indication of its thickness. An additional thickness measurement was then made by removing various thicknesses by chemical milling, according to BAC 5842, until the emittance value of the milled specimen had dropped back to that typical of the bare metal.

The instrument used for this study was the Lion Research Corporation Model 25B Emissometer. Briefly this instrument consists of a transducer head, a transducer output signal indicator, a thermo-electric cooler supply, a water circulater, and a vacuum system. These components are mounted in a console which is equipped with rubber wheels for portability.

In operation, the head (equipped with an eight-foot extension cable) is placed against the surface to be tested. Radiation from the surface enters the head and is absorbed by the blackened receiver disc of a thermopile. The receiver disc re-emits to its cooled surroundings causing the receiver disc to assume some temperature between the sample surface temperature and the temperature of the cold platten. The temperature of the thermopile receiver is dependent on the amount of radiation received which is related to both the emittance and temperature of the test surface. However, if the test surface temperature and the temperature of the cooled surfaces around the thermopile are kept constant, the thermopile output voltage is dependent only on the emittance of the test surface. The values of emittances are directly read off the meter scale mounted on the instrument console.

For each set of measurements the emissometer is calibrated against emittance standards, kept at the same temperature as the test specimens. This corrects for temperature changes from day to day, as well as for instrument response charges. The calibration standards are maintained by the Boeing Standards Group.

3.6 CHEMICAL TESTS

The tabulated data contains results of a number of chemical tests. These were carried out for two purposes: first to obtain information about the chemical composition of commercial products of unknown character, and second to determine the amounts (percent) of certain constituents, halogen atoms and ions, known to produce stress corrosion cracking of titanium.

3.6.1 Infrared Spectroscopy

Standard techniques were employed to measure the infrared spectra of interest. These included use of KBr pellets, and liquid film samples. Spectra were measured from 2.5-15 microns.

3.6.2 Chloride Analysis

Several methods of chloride analysis were used. These are methods used in the Boeing Quality Control Laboratories. They are listed below, and are described in detail in Appendix I.

- Bosler method For chlorides in machining lubricants
- Radiotracer silver method For soluble trace chlorides
- Beilstein test For qualitative detection only

- Parr bomb method For chlorides in dye penetrants and other combustible samples

- Sodium carbonate fusion For halides in non-combustible samples

3.6.3 Dissolved Gas Analysis

Titanium has an affinity for hydrogen, and hydrogen absorption can lead to embrittlement. Two closely related analytical methods were used to measure the hydrogen content of titanium specimens exposed to various test materials, in order to detect hydrogen intake. This data, in conjunction with the results of the modified Allison bend tests, permitted an evaluation of possible incompatibility due to hydrogen embrittlement.

3.6.3.1 Vacuum Fusion

Vacuum Fusion is a technique which is capable of determining the hydrogen, oxygen, and nitrogen contents of most metals. The analyzer is essentially an evacuated system containing a molten platinum bath which is held between 1800 degrees and 2100 degrees C. A carbon element and crucible are used to attain these temperatures. Weighed samples, when placed into the platinum bath, release their gaseous contents. Oxygen is converted to carbon monoxide.

The gas is immediately pumped on to the analytical section and a McLeod gauge reading taken. Hydrogen is oxidized to water and carbon monoxide to carbon dioxide by passage over hot copper oxide. After removing the hydrogen by conversion to water and cold trapping, another McLeod gauge reading is taken. A final reading is taken after the carbon dioxide is removed with Ascarite. The last reading is assumed to be nitrogen. By comparing these readings to those of a standard or to the gas law (analytical volumes already known), the quantities of gas per weight of sample may be calculated.

The sample size used in vacuum fusion is between 0.03 and 0.10 grams with an average of .06 grams. This relatively small sample size requires extreme care in surface cleaning and sample cutting. Volatile solvents, such as benzene, xylene, and acetone remove any organic contaminant, and filing removes any surface crust. Sanding should be avoided due to its tendency to produce high results.

Once the specimen is cleaned, a sample is cut with a chisel (the preferred method) or with a hacksaw, whose blade has been cleaned in benzene. Lathing and milling also seem to be acceptable; however, they are dependent on the care taken by shop personnel.

There are two means for standardization of vacuum fusion: (1) Theoretical calculations using the ideal gas law and (2) Comparison of sample data with data on standards of known gaseous content, processed identically.

1. Several attempts have been made to standardize vacuum fusion with the ideal gas law. Success has been achieved however, only under ideal conditions for hydrogen and oxygen. One major task in establishing a correlation between calculated results

using the gas law and empirical results based on known standards was the estimation of the gas collection volumes. These can now be accurately determined with a dosing stopcock and argon gas. A fresh platinum bath (one with negligible titanium contamination) is also required to prevent low results, indicating incomplete release of the gases from a contaminated bath.

2. The National Bureau of Standards has not produced an oxygen standard for titanium, although it has several pure titanium hydrogen standards. Therefore, it was advisable to standardize one of the NBS hydrogen standards for oxygen as a reference to use throughout this program. NBS 354 was chosen because of its reproducible oxygen readings and was established at 4500 ppm by many carefully conducted gas law determinations.

3.6.3.2 Hot Extraction Method

The accuracy attainable for hydrogen using the vacuum fusion was marginal for the purposes of this program. The hot extraction method utilizes the same test apparatus; however the test sample (approximately 100 mg) is heated to a lower temperature (1400C) in a carbon crucible. At this temperature, below the melting point of titanium, only hydrogen is evolved from the sample, which still retains its oxygen and nitrogen. The hydrogen can thus be determind directly from a single McLeod gage reading. Testing during this program indicated this to be a more precise analytical method.

3.7 METALLOGRAPHIC TESTS

Standard metallographic techniques were used for the evaluation of stress-corrosion, intergranular attack, etc., as required.

3.8 MACHINING

Standard machine shop equipment wasused to perform drilling, grinding, and milling on titanium specimens, as required in the evaluation of drilling or machining fluids.

4.0 INTERPRETATION OF TEST RESULTS

Compatibility ratings of A (compatible) or X (incompatible) were derived from the test data for each material listed in table 4, section 5. The criteria used in deriving these ratings are described below. For some materials the rating was derived from the results of several tests. In the tabulated data this is indicated by placing the compatibility rating on the same line as the name of the material, and listing the various test and results below. For other materials individual compatibility ratings were derived for each time-temperature-alloy exposure condition. This is indicated by placing the rating on the same line as the test decription.

In applying the compatibility ratings caution is required. An A rating should not be considered to imply compatibility under exposure conditions more severe than the maximum tested. A material compatible at several hundred degrees, its use temperature, may produce corrosion if not completely removed before a subsequent heat treating operation at a much higher temperature.

The most useful test for detecting incompatibility proved to be the U-bend test in its several modifications. In extreme cases incompatibility manifested itself by actual specimen fracture during exposure. In less severe cases varying degrees of surface attack could be detected by microscopic examination of the stressed surface following descaling. Table 1 lists five levels of severity of attack which could be distinguished by careful examination, and relates these to compatibility ratings of A or X. (Photographs illustrating SCC levels 2-5 are included in Vol. 1 of this report (ref. 2)).

TABLE 1.—LEVELS OF SEVERITY OF STRESS CORROSION CRACKING (SCC)

Level	Effect Observed	Compatibility Rating
	No Surface Effect	A
0	Staining, Shadowing, or Frosting	A
0	Etching or pitting smoother than 32 RHR	A
0	Etching or pitting rougher than 32 RHR	X
1	Slight SCC, a few short cracks	X
2	Moderate SCC, longer cracks, wider distribution than level 1	X
3	Widespread, general SCC	X
4	Massive general SCC	X
5	Complete failure, fracture	X

The criteria used to assign an A or X rating based on the Heimerl-Braski test are discussed in detail in reference 2. Briefly a rating of X is given if:

- One or more material exposure specimens fractured during exposure

- None of the material exposure specimens exhibited a deflection distance equal to or greater than the smallest deflection distance exhibited among the applicable control specimens.

- The statistical t value was greater than 3.7.

The statistical t value, for quadruplicate specimens, is defined by the equation

$$t = \frac{3.46\,(\bar{X}_c - \bar{X}_m)}{\left(\Sigma(X_c - \bar{X}_c)^2 + \Sigma(X_m - X_m)^2\right)^{1/2}}$$

c = Control (uncoated)

m = Material coated

X = Observed head travel

$\bar{X}$ = Average value for four specimens.

All materials not classified as X by one of the above are given an A rating.

Assignment of A or X ratings based upon chloride analysis proved to be difficult. Initially it had been planned to assign an X rating to materials containing more than 200 ppm of chlorine, since chloride ion is a major cause of titanium stress-corrosion cracking. Test results, however, especially on dye penetrant materials, showed poor correlation between chlorine levels and SCC. For this reason X ratings were not assigned based upon chlorine content alone without confirming evidence of surface attack. However it would be wise to be cautious in using materials containing high chlorine contents. Materials containing chlorinated solvents were rated X, even at temperatures where the pure solvents might be compatible, due to the possibility that chlorine could be retained in contact with the titanium to higher temperatures.

The results of the Allison bend testing are described in section 6. A bond energy difference of greater than 15 percent between control and test specimens probably indicates some surface change. The test detected oxide films formed during high temperature exposure, but no instances were found where large enough differences between exposed and control specimens in the same environment were found to indicate material incompatibility.

5.0 RESULTS OF COMPATIBILITY TESTING

The data obtained by application of the previously described test methods is tabulated in this section. An explanation of the coding used to identify test materials and parameters is given, together with an alphabetical index of the materials tested.

5.1 MATERIAL NUMBER CODE

The material number code consists of three index numbers. The materials tested for compatibility with titanium alloys have been divided into thirteen major classes, such as cleaner or scale conditioner, indicated by the first index number, beginning with 18. (Classes 1 - 17 are the flyaway materials covered in Vol. 1 of this report.) The second index number identifies specific subclasses such as protective coating, strippable. The third index number identifies one specific material within a class. Test data tabulated in the following section of this report is arranged in numerical order according to this code. Table 2 contains a key to the classes and subclasses.

5.2 ALPHABETICAL INDEX OF MATERIALS TESTED

Table 3 lists the materials tested for titanium compatibility in alphabetical order, with references to the location of the data in table 4. Vendors are identified in the tabulated data, and in table 3.

TABLE 2.–KEY TO CLASSES AND SUBCLASSES: MANUFACTURING AID MATERIALS

NUMBER	CLASS	SUBNUMBER	SUBCLASS
18	Cleaner		
19	Food		
20	Heat Treat Aid		
21	Machining Lubricant/Coolant		
22	Marking, Electrochemical		
		1	Cleaner
		2	Electrolyte
23	Marking, Temporary		
		1	Heat Treat Indicator
		2	Ink, Temporary Marking
		3	Pencil
24	Metal		
25	Paint		
		1	Leak Detection
		2	Protective
26	Penetrant Inspection Fluid		
		1	Developer
		2	Emulsifier/Remover
		3	Penetrant
27	Protective Coating		
		1	Heat Treat
		2	Spinning Compound
		3	Strippable (Temporary)
28	Salt		
29	Scale Conditioner		
		1	Aqueous
		2	Molton Salt
30	Solvent		
31	Stabilizer, Machining		
32	Stripper, Paint		
33	Tape, Temporary		

TABLE 3.–ALPHABETICAL INDEX OF MATERIALS TESTED

Material Name or Designation	Material Type	Vendor	Number Code
A-498	Protective Coating	Glidden-Metlseel	27.1.11
Acetic Acid	Solvent		30.1.1
Ardrox 985-P2	Penetrant Inspection Fluid	Ardrox Australia PTY, Ltd	26.3.1
Ardrox 9D-3	Penetrant Inspection Fluid	Ardrox Australia PTY, Ltd	26.1.1
Ardrox 9PR-4	Penetrant Inspection Fluid	Ardrox Australia PTY, Ltd	26.2.1
Ammonium Hydroxide	Solvent		30.1.2
A P C	Marking, Electrochemical	Marking Methods, Inc.	22.1.5
Aquamatic Universal Coolant	Machining Lubricant/Coolant	Molecular Products, Inc.	21.1.12
B-10	Marking, Electrochemical	Monode, Inc.	22.2.11
B-410	Machining Lubricant/Coolant	Texaco, Inc.	21.1.43
Barium Hydroxide	Machining Lubricant/Coolant		21.1.1
Barkerwax 38E	Stabilizer, Machining	Barker Enterprises	31.1.7
Blaisdell 551 Blue	Marking, Temporary	Blaisdell Co.	23.3.1
Boeing, Proprietary	Scale Conditioner	Boeing Co.	29.2.1
Bon Ami	Cleaner		18.1.2
Boric Acid	Protective Coating		27.1.4
Boric Acid GE SR350 Silicone	Protective Coating		27.1.5
Boron Nitride	Heat Treat Aid		20.1.1
Brandt 8224	Scale Conditioner	Brandt Chemical Co.	29.1.1
Butyl Alcohol	Solvent		30.1.3
Butyl Carbitol	Solvent	Union Carbide Corp.	30.1.4
Butyl Cellosolve	Solvent	Union Carbide Corp.	30.1.5
C-250	Machining Lubricant/Coolant	Mobil Oil Co.	21.1.13
C-300	Protective Coating	Fel-Pro Corp.	27.1.10
Carbon Tetrachloride	Solvent		30.1.6
Carus 303	Scale Conditioner	Carus Chem. Co.	29.2.2
Cerrolow 140	Stabilizer, Machining	Cerro de Pasco Corp.	31.1.8
Cerrolow 174	Stabilizer, Machining	Cerro de Pasco Corp.	31.1.9
Cool-Tool	Machining Lubricant/Coolant	Munroe Chem. Co.	21.1.25
Coollube No. 10	Machining Lubricant/Coolant	Pacific Chem. Co.	21.1.26
Covington Cote	Protective Coating	Timet Corp.	27.1.29
Crystal Cut 322	Machining Lubricant/Coolant	Hangsterfer's Labs, Inc.	21.1.5
Cut Max 569	Machining Lubricant/Coolant	E.F. Houghton & Co.	21.1.8
D-70	Penetrant Inspection Fluid	Met-L-Chek Co.	26.1.11
D-90	Penetrant Inspection Fluid	Sherwin, Inc.	26.1.19
D-100	Penetrant Inspection Fluid	Sherwin, Inc.	26.1.20
D-110	Penetrant Inspection Fluid	Sherwin, Inc.	26.1.21
D-113A	Penetrant Inspection Fluid	Sherwin, Inc.	26.1.22
D-492B	Penetrant Inspection Fluid	Shannon Luminous Materials Co.	26.1.12
D-492C	Penetrant Inspection Fluid	Shannon Luminous Materials Co.	26.1.13
D-493	Penetrant Inspection Fluid	Shannon Luminous Materials Co.	26.1.14

TABLE 3.–ALPHABETICAL INDEX OF MATERIALS TESTED (continued)

Material Name or Designation	Material Type	Vendor	Number Code
D-493A	Penetrant Inspection Fluid	Shannon Luminous Materials Co.	26.1.15
D-495A	Penetrant Inspection Fluid	Shannon Luminous Materials Co.	26.1.16
D-499B	Penetrant Inspection Fluid	Shannon Luminous Materials Co.	26.1.17
D-499C	Penetrant Inspection Fluid	Shannon Luminous Materials Co.	26.1.18
DD-2	Penetrant Inspection Fluid	Fluro-Chek Co.	26.1.2
DD-535	Penetrant Inspection Fluid	Sperry Div., Automated Industry, Inc.	26.1.24
Del-Chem 19AC	Stripper, Paint		3[illegible] 1.2
Delta 31	Protective Coating	Acheson Colloids, Inc.	27.1.1
DGS	Scale Conditioner	Kolene Co.	29.2.4
Dickson 1107 NH	Marking, Temporary	Dickson Ink Co.	23.2.1
Dickson 1307	Marking, Temporary	Dickson Ink Co.	23.2.2
Dickson 2101	Marking, Temporary	Dickson Ink Co.	23.2.3
Dickson 2307	Marking, Temporary	Dickson Ink Co.	23.2.4
Dickson 5507	Marking, Temporary	Dickson Ink Co.	23.2.5
DTE No. 24	Machining Lubricant/Coolant	Mobil Oil Co.	21.1.14
DTE No. 26	Machining Lubricant/Coolant	Mobil Oil Co.	21.1.15
DW 530	Penetrant Inspection Fluid	Sperry Div., Automated Industries, Inc.	26.1.25
Dy-Chek, Developer	Penetrant Inspection Fluid	Turco Products, Inc.	26.1.29
Dy-Chek, Emulsifier	Penetrant Inspection Fluid	Turco Products, Inc.	26.2.15
Dy-Chek, Penetrant	Penetrant Inspection Fluid	Turco Products, Inc.	26.3.37
E-56	Penetrant Inspection Fluid	Met-L-Chek Co.	26.2.8
E-59	Penetrant Inspection Fluid	Met-L-Chek Co.	26.2.9
E-142	Penetrant Inspection Fluid	Shannon Luminous Materials Co.	26.2.10
E-153	Penetrant Inspection Fluid	Shannon Luminous Materials Co.	26.2.11
E-157A	Penetrant Inspection Fluid	Shannon Luminous Materials Co.	26.2.12
E	Penetrant Inspection Fluid	Turco Products, Inc.	26.2.6
Eagle Oil No. 10	Machining Lubricant/Coolant	Richfield Oil Co.	21.1.38
Electrolyte 359L	Marking, Electrochemical	Electro Chem Etch Co.	22.2.1
Electrolyte 1	Marking, Electochemical	Electromark Corp.	22.2.3
Electrolyte 2	Marking, Electrochemical	Electromark Corp.	22.2.4
Electrolyte 4	Marking, Electrochemical	Electromark Corp.	22.2.5
Electrolyte 59-L	Marking, Electrochemical	Electromark Corp.	22.2.6
Electrolyte 353	Marking, Electrochemical	Electromark Corp.	22.2.7
Electromark 2-1	Marking, Electrochemical	Electromark Corp.	22.1.2
Electromark 2-2	Marking, Electrochemical	Electromark Corp.	22.1.3
ER 82	Penetrant Inspection Fluid	Sherwin, Inc.	26.2.13
ES & T	Marking, Electrochemical	Electro Chem Etch Co.	22.2.2
Ethanol	Solvent		30.1.7

TABLE 3.–ALPHABETICAL INDEX OF MATERIALS TESTED (continued)

Material Name or Designation	Material Type	Vendor	Number Code
Ethylene Glycol	Solvent		30.1.8
Epoxy Enamel	Paint	BMS 10-11	25.2.2
Epoxy Primer	Paint	BMS 10-11	25.2.1
F-10	Marking, Electrochemical	Monode, Inc.	22.2.12
F-20	Marking, Electrochemical	Monode, Inc.	22.2.13
FD-33	Penetrant Inspection Fluid	Testing Systems, Inc.	26.1.26
FH-420	Protective Coating	Acheson Colloids Co.	27.1.2
Fiber-Frax	Heat Treating Aid		20.1.2
FL-50	Penetrant Inspection Fluid	Testing Systems, Inc.	26.3.36
Fluoro Finder (Dry)	Penetrant Inspection Fluid	Testing Systems, Inc.	26.1.27
Fluoro Finder (Wet)	Penetrant Inspection Fluid	Testing Systems, Inc.	26.1.28
FP-22	Penetrant Inspection Fluid	Sherwin, Inc.	26.3.31
FP-90	Penetrant Inspection Fluid	Met-L-Chek	26.3.13
FP-91	Penetrant Inspection Fluid	Met-L-Chek	26.3.14
FP-92	Penetrant Inspection Fluid	Met-L-Chek	26.3.15
FP-93	Penetrant Inspection Fluid	Met-L-Chek	26.3.16
FP-95	Penetrant Inspection Fluid	Met-L-Chek	26.3.17
FPE-505	Penetrant Inspection Fluid	Sperry Div., Automated Industries, Inc.	26.3.35
Freon-Butyl Cellosolve	Machining Lubricant/Coolant	DuPont Co.	21.1.3
Freon 1301	Solvent	DuPont Co.	30.1.9
Freon MF	Solvent	DuPont Co.	30.1.10
Freon PCA	Solvent	DuPont Co.	30.1.11
Gage Cote 6	Protective Coating		27.1.30
GMC 895	Cleaner	Greater Mountain Chem. Co.	18.1.3
Grind-Tex B-410	Machining Lubricant/Coolant	Texaco Co.	21.1.43
Habcool 318	Machining Lubricant/Coolant	H & B Petroleum Co.	21.1.4
HD 200	Protective Coating	Kerns Pacific Corp.	27.1.15
HD 205	Protective Coating	Kerns Pacific Corp.	27.1.16
HD 6330	Protective Coating	Kerns Pacific Corp.	27.1.17
Hexane	Solvent		30.1.12
HM-3	Penetrant Inspection Fluid	Sherwin, Inc.	26.3.32
HM-225	Penetrant Inspection Fluid	Sherwin, Inc.	26.3.33
HM-405	Penetrant Inspection Fluid	Sherwin, Inc.	26.3.34
Hocut 237	Machining Lubricant/Coolant	E.F. Houghton & Co.	21.1.9
Houghto Safe 620	Machining Lubricant/Coolant	E.F. Houghton & Co.	21.1.10
HS 8171 PS	Tape, Temporary	Richmond Corp.	33.1.6
Iodine, Toluene, and SAE 10	Machining Lubricant/Coolant		21.1.11
Ink	Marking, Temporary	Esterbrook Co.	23.2.9
Ink	Marking, Temporary	Sharpie Co.	23.2.12
Jarvie 40	Stabilizer, Machining	Jarvie Paint Co.	31.1.10
K-58-C	Stripper, Paint	Keelite Corp.	32.1.1
Kalcote XP	Protective Coating	California Coatings Co.	27.1.6
Kalgard FL (Kalube FL)	Protective Coating	California Coatings Co.	27.1.8

TABLE 3.–ALPHABETICAL INDEX OF MATERIALS TESTED (continued)

Material Name or Designation	Material Type	Vendor	Number Code
Kalgard FL-40 (Kalube FL-40)	Protective Coating	California Coatings Co.	27.1.7
Kelite 9	Paint	Kelite Chem. Co.	25.1.2
Kirksite	Metal		24.1.1
L-028	Penetrant Inspection Fluid	Sherwin, Inc.	26.1.23
Lead	Metal		24.1.2
LF-22	Protective Coating	Lubri-Film, Inc.	27.1.18
LF-32	Protective Coating	Lubri-Film, Inc.	27.1.19
LF-70	Protective Coating	Lubri-Film, Inc.	27.1.20
LF-75	Protective Coating	Lubri-Film, Inc.	27.1.21
LF-80	Protective Coating	Lubri-Film, Inc.	27.1.22
LF-500	Protective Coating	Lubri-Film, Inc.	27.1.23
LF-600	Protective Coating	Lubri-Film, Inc.	27.1.24
LF-700	Protective Coating	Lubri-Film, Inc.	27.1.25
M-3	Marking, Temporary	Marsh Co.	23.2.10
3M 850	Tape (Temporary)	3M Co.	33.1.1
Major Clean	Cleaner		18.1.4
Marking Methods 5	Marking, Electrochemical	Marking Methods, Inc	22.1.4
Mercury	Metal		24.1.3
Met 25	Machining Lubricant/Coolant	Mobil Oil Co.	21.1.16
Methanol	Solvent		30.1.13
Methyl Chloroform	Solvent		30.1.14
Methyl Ethyl Ketone	Solvent		30.1.15
Milk	Food		19.1.1
Missile Lube No. 1	Machining Lubricant/Coolant	Hangsterfer's Labs, Inc.	21.1.6
Missile Lube No. 5	Machining Lubricant/Coolant	Hangsterfer's Labs, Inc.	21.1.7
Mist No. 36	Machining Lubricant/Coolant	Mobil Oil Co.	21.1.17
MSC No. 3	Marking, Electrochemical	Monode, Inc.	22.1.6
MSC No. 5	Marking, Electrochemical	Monode, Inc.	27.1.7
Mystic 5863	Tape, Temporary	Mystic Co.	33.1.3
Mystic 6110	Tape, Temporary	Mystic Co.	33.1.4
Nad Developer	Penetrant Inspection Fluid	Turco Products	26.1.30
Neutracleaner No. 1	Marking, Electrochemical	Electrochemical Etch Co.	22.1.1
Nevr-Dull	Cleaner	George Basch Co.	18.1.5
Orange Detector Paint	Paint	Fuller Co.	25.1.1
Organoceram 1-1043	Protective Coating	Organocerams, Inc.	27.3.2
Organoceram 1-1044	Protective Coating	Organocerams, Inc.	27.3.3
Organoceram 1-2020	Protective Coating	Organocerams, Inc.	27.3.4
P3F	Penetrant Inspection Fluid	NAA-Rockwell	26.3.18
P3F-3	Penetrant Inspection Fluid	NAA-Rockwell	26.3.19
P5F-1	Penetrant Inspection Fluid	NAA-Rockwell	26.3.21
P5F-2.5	Penetrant Inspection Fluid	NAA-Rockwell	26.3.21
P5F-3	Penetrant Inspection Fluid	NAA-Rockwell	26.3.22
P-40	Penetrant Inspection Fluid	Turco Products	26.3.38
P-133	Penetrant Inspection Fluid	Shannon Luminous Products, Inc.	26.3.23

TABLE 3.–ALPHABETICAL INDEX OF MATERIALS TESTED (continued)

Material Name or Designation	Material Type	Vendor	Number Code
P-133A	Penetrant Inspection Fluid	Shannon Luminous Products, Inc.	26.3.24
P-134	Penetrant Inspection Fluid	Shannon Luminous Products, Inc.	26.3.25
P-134A	Penetrant Inspection Fluid	Shannon Luminous Products, Inc.	26.3.26
P-135	Penetrant Inspection Fluid	Shannon Luminous Products, Inc.	26.3.27
P-148A	Penetrant Inspection Fluid	Shannon Luminous Products, Inc.	26.3.28
P-149	Penetrant Inspection Fluid	Shannon Luminous Products, Inc.	26.3.29
P-150	Penetrant Inspection Fluid	Shannon Luminous Products, Inc.	26.3.30
Pannier 1001 Red	Marking, Temporary	Pannier Ink Co.	23.2.7
Pasa-Jell 107C-7	Cleaner	Semco Sales & Service Corp.	18.1.1
PE 520	Penetrant Inspection Fluid	Sperry Div., Automated Industries, Inc.	26.2.14
Pencil, Blue 551	Marking, Temporary	Blaisdell Co.	23.3.1
Perchlorethylene	Solvent		30.1.6
Permacel 733	Tape, Temporary	Permacel Co.	33.1.5
PF (Rigidax)	Stabilizer, Machining	M. Argüeso & Co., Inc.	31.1.2
Polyurethane Enamel	Paint	BMS 10-60	25.2.3
Pretreat	Protective Coating	Turco Products, Inc.	27.1.28
n-Propyl Alcohol	Solvent		30.1.17
iso-Propyl Alcohol	Solvent		30.1.18
Propylene Glycol	Solvent		30.1.19
Project-A-Mark	Marking, Temporary	Marsh Co.	23.2.11
RA-536	Protective Coating	Glidden-Metlseel	27.1.12
RA-537	Protective Coating	Glidden-Metlseel	27.1.13
RA-538	Protective Coating	Glidden-Metlseel	27.1.14
Rapid Top	Machining Lubricant/Coolant	Relton Corp.	21.1.37
Rigidax Blue F	Stabilizer, Machining	M. Argüeso & Co., Inc.	31.1.1
Rigidax PF	Stabilizer, Machining	M. Argüeso & Co., Inc.	31.1.2
Rigidax W1 Blue	Stabilizer, Machining	M. Argüeso & Co., Inc.	31.1.3
Rigidax WI Green	Stabilizer, Machining	M. Argüeso & Co., Inc.	31.1.4
Rigidax W1 NF	Stabilizer, Machining	M. Argüeso & Co., Inc.	31.1.5
Rigidax YF	Stabilizer, Machining	M. Argüeso & Co., Inc.	31.1.6
SC-44	Marking, Electrochemical	Electromark Corp.	22.2.8
SC-82	Marking, Electrochemical	Electromark Corp.	22.2.9
SC-277-2	Protective Coating	Spraylat Corp.	27.3.5
SC-1071	Protective Coating	Spraylat Corp.	27.3.6
Silver Chloride	Salt		28.1.1
Silver Iodide	Salt		28.1.2
Silver Nitrate	Salt		28.1.3
Snoop No. 3	Paint	Nupro Corp.	25.1.3
Sodium Chloride	Salt		28.1.4

TABLE 3.–ALPHABETICAL INDEX OF MATERIALS TESTED (continued)

Material Name or Designation	Material Type	Vendor	Number Code
Sodium Hydroxide	Scale Conditioner		29.1.2
Sodium Nitrite	Machining Lubricant/Coolant		21.1.40
Solvac 2032	Machining Lubricant/Coolant	Mobil Oil Co.	21.1.18
Solvac NP	Machining Lubricant/Coolant	Mobil Oil Co.	21.1.19
Sultran 176-M	Machining Lubricant/Coolant	Mobil Oil Co.	21.1.20
T-10 (Cimcool)	Machining Lubricant/Coolant	Cincinatti Milling Machine Company	21.1.2
T-10	Marking, Electrochemical	Marking Methods, Inc.	22.2.10
T-50	Protective Coating	Everlube Corp. of America	27.1.9
Tap Magic	Machining Lubricant/Coolant	Staco Corp.	21.1.41
Tapzol 410	Machining Lubricant/Coolant	Rust-Lick Corp.	21.1.39
Tempilstik 1150°F	Marking, Temporary	Tempilstik Co.	23.1.1
Tempilstik 1350°F	Marking, Temporary	Tempilstik Co.	23.2.2
TJ-73	Machining Lubricant/Coolant	Mobil Oil Co.	21.1.21
Trichlorethylene	Solvent		30.1.20
Trikut DS	Machining Lubricant/Coolant	Pemaco, Inc.	21.1.27
Trikut DSL	Machining Lubricant/Coolant	Pemaco, Inc.	21.1.28
Trikut GO	Machining Lubricant/Coolant	Pemaco, Inc.	21.1.29
Trikut GOH	Machining Lubricant/Coolant	Pemaco, Inc.	21.1.30
Trikut HO	Machining Lubricant/Coolant	Pemaco, Inc.	21.1.31
Trikut HOL	Machining Lubricant/Coolant	Pemaco, Inc.	21.1.32
Trikut OBH	Machining Lubricant/Coolant	Pemaco, Inc.	22.1.33
Trikut OHD	Machining Lubricant/Coolant	Pemaco, Inc.	22.1.34
Trikut SHD	Machining Lubricant/Coolant	Pemaco, Inc.	22.1.35
Trikut TPO	Machining Lubricant/Coolant	Pemaco, Inc.	22.1.36
Tuck 90W	Tape, Temporary	Tuck Tape Co.	33.1.7
Turco 520	Paint	Turco Products, Inc.	25.1.4
Turco 379-40C	Protective Coating	Turco Products, Inc.	27.1.26
Turco 379-40D	Protective Coating	Turco Products, Inc.	27.1.27
Turco 4316	Scale Conditioner	Turco Products, Inc.	29.1.3
Turco 4338	Scale Conditioner	Turco Products, Inc.	29.1.4
Turco Pretreat	Protective Coating	Turco Products, Inc.	27.1.28
Type A Red	Marking, Temporary	Magic Marker Corp.	23.2.6
Type A Red	Marking, Temporary	Speedry Chemical Prod. Co.	23.2.8
Vactra No. 4	Machining Lubricant/Coolant	Mobil Oil Co.	21.1.22
Vactra Oil Light	Machining Lubricant/Coolant	Mobil Oil Co.,	21.1.23
Vantrol 31-130A	Machining Lubricant/Coolant	Vantrol Corp.	21.1.44
Velocite No. 5	Machining Lubricant/Coolant	Mobil Oil Co.	21.1.24
Virgo	Scale Conditioner	Hooker Chem. Co.	29.2.3
W1 Blue, Rigidax	Stabilizer, Machining	M. Argüeso & Co., Inc.	31.1.3
WI Green, Rigidax	Stabilizer, Machining	M. Argüeso & Co., Inc.	31.1.4
W1 NF, Rigidax	Stabilizer, Machining	M. Argüeso & Co., Inc.	31.1.5
Warren No. 1	Protective Coating	Warren Chemical Mfg. Co.	27.2.1
Warren No. 2	Protective Coating	Warren Chemical Mfg. Co.	27.2.2
Water	Solvent		30.1.22
WD	Penetrant Inspection Fluid	Fluoro-Chek Co.	26.1.3

TABLE 3.–ALPHABETICAL INDEX OF MATERIALS TESTED (continued)

Material Name or Designation	Material Type	Vendor	Number Code
White Oil No. 3, NF (Chevron)	Machining Lubricant/Coolant	Standard Oil Co. of Calif.	21.1.42
WK 308X	Protective Coating	Acheson Colloids Co.	27.1.3
WP-1	Penetrant Inspection Fluid	Turco Products, Inc.	26.3.39
WP-167	Penetrant Inspection Fluid	Turco Products, Inc.	26.3.40
WP-167R	Penetrant Inspection Fluid	Turco Products, Inc.	26.3.41
XP Kalcote	Protective Coating	California Coatings, Inc.	27.1.6
Y 9241	Tape, Temporary	3M Corp.	33.1.2
YF, Rigidax	Stabilizer, Machining	M. Argüeso & Co., Inc.	31.1.6
ZE-3	Penetrant Inspection Fluid	Magnaflux Corp.	26.2.2
ZE-4	Penetrant Inspection Fluid	Magnaflux Corp.	26.2.3
ZE-4A	Penetrant Inspection Fluid	Magnaflux Corp.	26.2.4
ZE-4B	Penetrant Inspection Fluid	Magnaflux Corp.	26.2.5
ZE-6 (ZR-1)	Penetrant Inspection Fluid	Magnaflux Corp.	26.2.6
ZL-2	Penetrant Inspection Fluid	Magnaflux Corp.	26.3.2
ZL-2A	Penetrant Inspection Fluid	Magnaflux Corp.	26.3.3
ZL-16	Penetrant Inspection Fluid	Magnaflux Corp.	26.3.4
ZL-17	Penetrant Inspection Fluid	Magnaflux Corp.	26.3.5
ZL-17A	Penetrant Inspection Fluid	Magnaflux Corp.	26.3.6
ZL-18	Penetrant Inspection Fluid	Magnaflux Corp.	26.3.7
ZL-22	Penetrant Inspection Fluid	Magnaflux Corp.	26.3.8
ZL-22A	Penetrant Inspection Fluid	Magnaflux Corp.	26.3.9
ZL-22I	Penetrant Inspection Fluid	Magnaflux Corp.	26.3.10
ZL-30	Penetrant Inspection Fluid	Magnaflux Corp.	26.3.11
ZL-30A	Penetrant Inspection Fluid	Magnaflux Corp.	26.3.12
ZP-4	Penetrant Inspection Fluid	Magnaflux Corp.	26.1.4
ZP-4A	Penetrant Inspection Fluid	Magnaflux Corp.	26.1.5
ZP-5	Penetrant Inspection Fluid	Magnaflux Corp.	26.1.6
ZP-9	Penetrant Inspection Fluid	Magnaflux Corp.	26.1.7
ZP-11	Penetrant Inspection Fluid	Magnaflux Corp.	26.1.8
ZP-20	Penetrant Inspection Fluid	Magnaflux Corp.	26.1.9
ZP-X432 (ZP-13)	Penetrant Inspection Fluid	Magnaflux Corp.	26.1.10
ZR-2	Penetrant Inspection Fluid	Magnaflux Corp.	26.2.7

5.3 TABULATION OF TEST DATA

Experimental test data is listed in table 4, pages 30 to 83, arranged in order of index numbers. Notations used in the table are as follows:

- Test. The various tests used are described in section 3 of this report.

- Test Parameters

  Titanium alloys are identified as follows:
  CP Commercially pure (unalloyed)
  4Al-3Mo-1V or 4-3-1
  5Al-2.5Sn or 5-2.5
  6Al-4V or 6-4
  8 Al-1Mo-1V or 8-1-1 where Al = aluminum, etc.

  Titanium alloy heat-treat conditions are designated as follows:

I (or Cond. I)	Condition I mill anneal (According to XBMS7-158 for 6-4 and 8-1-1)
II (or Cond. II)	Solution Treated (ST)
III (or Cond. III)	Solution Treated, Aged at 1000°F
IV (or Cond. IV)	Solution Treated, Aged at 1250°F
V (or Cond. V)	Duplex Anneal

- Specimens

  Thickness was 0.050-inches unless otherwise specified. Dimensions according to directions for specific test. Number of specimens per test as follows (Minimum of two control specimens per test), unless otherwise specified in table 4.

Test	No. of Specimens (Per exposure condition per alloy)
Allison Bend	5 or more
Emittance	3
Flat Sheet Exposure	(Controlled by Allison Bend)
Gas Analysis	3
Resin Kettle	2
U-Bend (Ambient or Elev. Temp.)	2

- Results (See section 4 for more detail)

  U-Bend – Failure – Specimen broke into two parts
  SCC – Stress-corrosion cracking observed*
  No SCC or surface effect – Surface examined microscropically showed no attack, no metallographic examination done

*For definition of numerical levels see table 1.

- Compatibility

A = Compatible under test conditions employed, e.g. no excessive surface etch, SCC, or embrittlement of alloy tested.
X = Incompatible, e.g. excessive etch, SCC, or embrittlement observed.

TABLE 4.–COMPATIBILITY DATA, MANUFACTURING AID MATERIALS

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
			Material Class Cleaner			
18.1.1	Pasa Jell 107C-7 (Semco Sales and Service Co.)	Single U-Bend	6-4 I	75°F, 768 Hours	Superficial etch	A
18.1.2	Bon-Ami	Single U-Bend	6-4 I	1000°F, 4 Hours	Slight surface etch	A
18.1.3	GMC 895 (Greater Mountain Chemical Co.)	Flat Sheet Exposure	6-4 I	170°F, 1 Hr, Single specimen	No visible surface effect	A (at operating temperature, 170-190°F)
		Allison Bend	6-4 I	170°F, 1 Hr, 3 specimens, 0.40"	Bend energy, In-lbs Control 18 Test 20	
		Gas Analysis	6-4 I	170°F, 1 Hr.	Gas content, ppm H_2 O_2 Control 73 1220 Test 74 1225	
		Metallograph	6-4 I	170°F, 1 Hr.	No intergranular attack	
18.1.4	Major Clean	Single U-Bend	6-4 I	1000°F, 4 Hr., Resin Kettle	Slight surface etch	X*
		Single U-Bend	6-4 I	1400°F, 45 Min., Resin Kettle	Severe etch and pits	X*
18.1.5	Nevr-Dull (George Basch Co.)	Chemical Analysis (IR)			Diatomaceous earth, a long-chain hydrocarbon, and a carbonyl group	A
		Single U-Bend	6-4 I	850°F, 4 Hrs.	No SCC or surface effect	
			Material Class Food			
19.1.1	Milk	Resin Kettle (35 ml milk)	4-3-1 I	850°F, 8 Hr.	No SCC or surface effect	A
			6-4 I	850°F, 8 Hr.	No SCC or surface effect	
			8-1-1 I	850°F, 8 Hr.	No SCC or surface effect	

*Approved for use only if residual material is completely removed.

TABLE 4.—COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Heat Treating Aid				
20.1.1	Boron nitride	Single U-Bend	6-4 I	1475°F, 3 Hrs. as received	Severe etching and grooving	X
		Single U-Bend	6-4 I	1475°F, 3 Hrs. 1:1 H_2O	Severe etching and grooving	X
		Single U-Bend	6-4 I	1400°F, 30 Min., as received	Etching	X
		Single U-Bend	6-4 I	1400°F, 30 Min., 1:1 H_2O	Circle of etching	X
20.1.2	Fiberfrax	Heimerl-Braski	6-4 I	1300°F, 15 Min., 84 Ksi stress	t = 0.56	A
		Single U-Bend	6-4 I	1000°F, 4 Hrs.	No surface effect	A
		Material Class Machining Lubricant/Coolant				
21.1.1	Barium Hydroxide (5% Solution)					X*
		Machine Shop Operations	8-1-1 I			
		1. Gas Analysis		Metal from inside drilled holes	Gas Content, ppm: H_2 / O_2 — Control 39 / 1165; Test 53 / 739	
				Metal from milled specimens	Control 39 / 1165; Test 20 / 660	
				Metal from specimens following grinding	Control 39 / 1165; Test 29 / 800	
		2. Metallographic Analysis		On each of above specimen types	No microstructure alterations	
		1. Gas Analysis	8-1-1 V	Metal from inside drilled holes	Gas Content, ppm: H_2 / O_2 — Control 87 / 1020; Test 53 / 739	

*Incompatible due to toxicity, not to corrosivity for titanium.

TABLE 4.—COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Machining Lubricant/Coolant				
21.1.1 (cont'd)	Barium Hydroxide (5% Solution)			Metal from milled specimens	Gas Content, ppm H_2 O_2 Control 87 1020 Test 60 660	
				Metal from specimens following grinding	Control 87 1020 Test 69 800	
		2. Metallographic Analysis		On each of above specimens	No microstructure alterations	
21.1.2	Cimcool T-10 (Cincinatti Milling Machine Co.)	U-Bend	6-4 I	1000°F, 4 Hrs (2 specimens)	Severe surface etch	X
21.1.3	Freon-Butyl Cellosolve (DuPont Co.)					A
		Machine Shop Operations	8-1-1 I			
		1. Gas Analysis		Metal from inside drilled holes	Gas Content, ppm H_2 O_2 Control 39 1165 Test 56 600	
				Metal from milled specimens	Control 39 1165 Test 19 555	
		2. Metallographic Analysis		On each of above specimen types	No microstructure alterations	
		1. Gas Analysis	8-1-1 V	Metal from inside drilled holes	Gas Content, ppm H_2 O_2 Control 87 1020 Test 49 747	
				Metal from milled specimens	Control 87 1020 Test 51 686	

TABLE 4.—COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Machining Lubricant/Coolant				
21.1.4	Habcool 318 (H & B Petroleum Co.)					X
		Chloride Analysis		Bosler Method	3.2% chlorine	
		Resin Kettle (43 ml coolant)	4-3-1 I	850°F, 8 Hrs.	No SCC or surface effect	
			6-4 I	850°F, 8 Hrs.	Specimens broke	
			8-1-1 I	850°F, 8 Hrs.	Specimens broke	
		Flat Sheet Exposure	8-1-1 I	550°F, 40 Min.	No visible surface effect	
		Gas Analysis	8-1-1 I	550°F, 40 Min.	Gas Content, ppm H_2 O_2 Control 55 850 Test 60 815	
21.1.5	Crystal Cut No. 322 (Hangsterfer's Laboratories, Inc.)	Single U-Bend	6-4 I	1000°F, 4 Hr.	SCC, Level 1	X
21.1.6	Missile Lube No. 1 (Hangsterfer's Laboratories, Inc.)	Single U-Bend	6-4 I	1000°F, 4 Hr.	No effect	A
21.1.7	Missile Lube No. 5 (Hangsterfer's Laboratories, Inc.)	Single U-Bend	6-4 I	1000°F, 4 Hr.	SCC, Level unrecorded	X
21.1.8	Cut-Max 569 (E.F. Houghton & Co.)					X
		Chloride		From company literature	Contains chlorinated solvents	

TABLE 4.—COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Machining Lubricant/Coolant				
21.1.8 (cont'd)		Machine Shop Operations	8-1-1 I			
		1. Gas Analysis		Metal from milled specimens	Gas Content, ppm H_2 O_2 Control 39 1165 Test 31 726	
		2. Metallographic Analysis		Metal from milled specimens	No microstructure alterations	
			8-1-1 V			
		1. Gas Analysis			Gas Content, ppm H_2 O_2 Control 87 1020 Test 69 676	
		2. Metallographic Analysis		Metal from milled	No microstructure alterations	
21.1.9	Hocut 237 (E.F. Houghton & Co.)					A
		Chloride Analysis		Bosler Method	None detected	
		Drip Corrosion Test	6-4 I	550°F, 16 Hrs.	No visible surface effect	
		Allison Bend	6-4 I	Specimens from drip corrosion test (6 specimens, 0.040" thick)	Bend Energy, In-lbs Control 83 Test 59	
		Flat Sheet Exposure	6-4 I	550°F, 40 Min.	No visible surface effect	
		Allison Bend	6-4 I	Specimens from flat sheet exposure (8 specimens, 0.040" thick)	Bend Energy, In-lbs Control 98 Test 92	

TABLE 4.–COMPATIBILITY DATA, MANUF. :TURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Machinir		oricant/Coolant		
21.1.9 (cont'd)		Gas Analysis	6-4 I	O ı specimens aft r Allison bend	Gas Content, ppm H_2 O_2 Control 55 850 Test 55 885	
		Machine Shop Operations	8-1-1 I			
		1. Gas Analysis		Metal from inside drilled holes	Gas Content, ppm H_2 O_2 Control 39 1165 Test 50 800	
				Metal from ground specimens	Test 50 850	
				Metal from milled specimens	Test 19 680	
		2. Metallographic Analysis	8-1-1 I	On each of above specimen types	No microstructure alterations	
			8-1-1 V			
		1. Gas Analysis		Metal from inside drilled holes	Gas Content, ppm H_2 O_2 Control 87 1020 Test 45 619	
				Metal from ground specimens	Test 74 660	
				Metal from milled specimens	Test 56 620	
		2. Metallographic Analysis		On each of above specimen types	No microstructure alterations	
21.1.10	Houghto Safe 620 (Houghton Co.)	Single U Bend	6-4 I	1000°F, 4 Hrs.	Slight surface effect	A

TABLE 4.–COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Machining Lubricant/Coolant				
21.1.11	Iodine (1%) Toluene (4%) SAE 10 (95%)	Resin Kettle	6-4 I 8-1-1 I	$850^\circ F$, 6 Hrs. $850^\circ F$, 6 Hrs.	No SCC or surface effect No SCC or surface effect	A
21.1.12	Aquamatic Universal Coolant (Molecular Products, Inc.)	U-Bend	6-4 I	$1000^\circ F$, 4 Hrs.	Severe SCC	X
21.1.13	C-250 (Mobil Oil Co.)	Chloride Flat Sheet Exposure	6-4 I	Beilstein $550^\circ F$, 40 Min.	Positive No visible surface effect	A
		Allison Bend	6-4 I	$550^\circ F$, 40 Min., 8 specimens	Bend Energy, In-lbs Control 98 Test 98	
		Gas Analysis	6-4 I	On Allison Bend specimens (2) after testing	Gas Content, ppm H_2 O_2 Control 55 850 Test 52 890	
21.1.14	DTE No. 24 (Mobil Oil Co.) BAC No. 10	Resin Kettle	6-4 I 8-1-1 I	$850^\circ F$, 1.5 Hr. $850^\circ F$, 1.5 Hr.	No SCC or surface effect No SCC or surface effect	A
21.1.15	DTE No. 26 (Mobil Oil Co.) BAC No. 12	Resin Kettle	6-4 I 8-1-1 I	$850^\circ F$, 2 Hr. $850^\circ F$, 2 Hr.	No SCC or surface effect No SCC or surface effect	A
21.1.16	MET 25 (Mobil Oil Co.)	Chloride Flat Sheet	6-4 I	Bosler Method $550^\circ F$, 40 Min.	600 ppm Chloride No visible surface effect	A

TABLE 4.–COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Machining Lubricant/Coolant				
21.1.16 (cont'd)		Allison Bend	6-4 I	On flat sheet specimen (6)	Bend Energy, In-lbs Control 83 Test 84	
21.1.17	MIST No. 36 (Mobil Oil Co.) BAC No. 25	Resin Kettle (35 ml sample)	6-4 I 8-1-1 I	850°F, 2 Hr., 2 specimens 850°F, 2 Hr.	No SCC or surface effect No SCC or surface effect	A
21.1.18	Solvac 2032 (Mobil Oil Co.)	Chemical Content Resin Kettle	 6-4 I 8-1-1 I	Vendor Literature 850°F, 3 Hr. 850°F, 3 Hr.	1.7% sulfur No SCC or surface effect No SCC or surface effect	A
21.1.19	Solvac NP (Mobil Oil Co.)	Resin Kettle	6-4 I 8-1-1 I	850°F, 2 Hr. 850°F, 2 Hr.	No SCC or surface effect No SCC or surface effect	A
21.1.20	Sultran 176-M (Mobil Oil Co.)	U-Bend	6-4 I	1000°F, 4 Hrs.	No SCC or surface effect	A
21.1.21	TJ-73 (Mobil Oil Co.)	Machine Shop 1. Gas Analysis	8-1-1 I	Metal from inside drilled holes	Gas Analysis, ppm H_2 O_2 Control 39 1165 Test 50 775	A
		2. Metallographic Analysis	8-1-1 I	On above metal	No microstructure alterations	

TABLE 4.—COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Machining Lubricant/Coolant				
21.1.21 (cont'd)		1. Gas Analysis	8-1-1 V	Metal from inside drilled hole	Gas Analysis, ppm: H_2 / O_2 — Control 87 / 1020; Test 43 / 564	
				Metal from milled specimens	Test 60 / 763	
		2. Metallographic Analysis		On metal from milled and drilled specimens	No microstructure alterations	
21.1.22	Vactra No. 4 (Mobil Oil Co.) BAC No. 24	Resin Kettle	6-4 I 8-1-1 I	850°F, 1.5 Hr. 850°F, 1.5 Hr.	No SCC or surface effect No SCC or surface effect	A
21.1.23	Vactra Oil Light (Mobil Oil Co.) BAC No. 2	U-Bend	6-4 I	1000°F, 4 Hr.	No SCC or surface effect	A
21.1.24	Velocite No. 5 (Mobil Oil Co.) BAC No. 63	Resin Kettle	6-4 I 8-1-1 I	850°F, 1.5 Hr. 850°F, 1.5 Hr.	No SCC or surface effect No SCC or surface effect	A
21.1.25	Cool Tool (Munroe Chem. Co.)	U-Bend	6-4 I	1000°F, 4 Hrs.	No SCC or surface effect	A
21.1.26	Coolube No. 10 (Pacific Chemical Co.)	U-Bend	6-4 I	1000°F, 4 Hrs.	Slight SCC and pits	X
21.1.27	Tricut DS (Pemaco, Inc.)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	SCC, Level No. 3	X

TABLE 4.–COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Machining Lubricant/Coolant				
21.1.28	Tricut DSL (Pemaco)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	SCC, Level No. 3	X
21.1.29	Tricut GO	Single U-Bend	6-4 I	1000°F, 4 Hrs.	SCC, Level No. 3	X
21.1.30	Tricut GOH	Single U-Bend	6-4 I	1000°F, 4 Hrs.	SCC, Level No. 3	X
21.1.31	Tricut HO	Single U-Bend	6-4 I	1000°F, 4 Hrs.	SCC, Level No. 3	X
21.1.32	Tricut HOL	Single U-Bend	6-4 I	1000°F, 4 Hrs.	SCC, Level No. 3	X
21.1.33	Tricut OBH	Single U-Bend	6-4 I	1000°F, 4 Hrs.	SCC, Level No. 3	X
21.1.34	Tricut OHD	Single U-Bend	6-4 I	1000°F, 4 Hrs.	SCC, Level No. 3	X
21.1.35	Tricut SHD	Single U-Bend	6-4 I	1000°F, 4 Hrs.	SCC, Level No. 3	X
21.1.36	Tricut TPO	Single U-Bend	6-4 I	1000°F, 4 Hrs.	SCC, Level No. 3	X
21.1.37	Rapid Tap (Relton Corp.)					X
		Chloride		Company Literature	Contains 1, 1, 1-Tri-chloroethane	
		Resin Kettle	6-4 I	850°F, 8 Hrs.	No SCC	
			8-1-1 I	850°F, 8 Hrs.	Specimens Broke	
		Flat Sheet Exposure	6-4 I	550°F, 40 Min.	No visible surface effect	
		Allison Bend	6-4 I	550°F, 40 Min.	Bend Energy, In-lbs Control 98 Test 90	
		Gas Analysis	6-4 I	On Allison Bend, 2 specimens	Gas Content, ppm H_2 O_2 Control 55 850 Test 60 780	
21.1.38	Eagle Oil No. 10 (Richfield Oil Co.)	U-Bend	6-4 I	1000°F, 4 Hrs.	No. SCC or surface effect	A
21.1.39	Tapzol 410 (Rust-Lick Corp.)					A
		Chloride		Beilstein	Negative	

TABLE 4.–COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Machining Lubricant/Coolant				
21.1.39 (cont'd)		Flat Sheet Exposure	6-4 I	550°F, 40 Min.	No visible surface effect	
		Allison Bend		Specimens (8) from flat sheet exposure	Bend Energy, In-lbs Control 98 Test 90	
		Gas Analysis		On Allison Bend specimens (4)	Gas Content, ppm H_2 O_2 Control 55 850 Test 56 800	
21.1.40	Sodium Nitrite 5% solution of C.P.	U-Bend	6-4 I	1000°F, 4 Hr.	No SCC or surface effects on initial testing. Subsequent tests gave slight to severe surface etch	A–X
		Machine Shop Operations 1. Gas Analysis	8-1-1 I	Metal specimens after grinding	Gas Content, ppm H_2 O_2 Control 39 1165 Test 28 712	
		2. Metallographic Analysis	8-1-1 I	On above specimens	No microstructure alterations	
		1. Gas Analysis	8-1-1 V	Metal specimen after grinding	Gas Content, ppm H_2 O_2 Control 87 1020 Test 74 728	
		2. Metallographic	8-1-1 V	On above specimens	No microstructure alterations	

TABLE 4.—COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Machining Lubricant/Coolant				
21.1.41	Tap Magic (Staco Corp.)					X
		Chloride		Company Literature	Contains 1, 1, 1-Tri-chloroethane	
		Flat Sheet Exposure	6-4 I	550°F, 40 Min.	No visible surface effect	
		Allison Bend	6-4 I	Flat sheet exposure specimens	Bend Energy, In-lbs Control 98 Test 88	
		Gas Analysis	6-4 I	On Allison bend specimens	Gas Content, ppm H_2 O_2 Control 55 850 Test 57 845	
21.1.42	White Oil No. 3 NF (Standard Oil Co. of California)	Machine Shop Operation				A
		1. Gas Analysis	8-1-1 I	Analysis on <u>milled</u> specimens	Gas Content, ppm H_2 O_2 Control 39 1165 Test 26 790	
		2. Metallographic Analysis	8-1-1 I	On above specimens	No microstructure alterations	
			8-1-1 V			
		1. Gas Analysis		Analysis on <u>milled</u> specimens	Gas Content, ppm H_2 O_2 Control 87 1020 Test 73 668	
		2. Metallographic Analysis	8-1-1 V	On above specimens	No microstructure alterations	

TABLE 4.– COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Machining Lubricant/Coolant				
21.1.43	Grind Tex B-410 (Texaco Co.)					A
		Chloride		Bosler method	800 ppm Chloride	
		Flat Sheet Exposure	6-4 I	550°F, 40 Min	No visible surface effect	
		Allison Bend		On flat sheet exposure specimens	Bend Energy, In-lbs Control 98 Test 92	
		Gas Analysis		On Allison specimens	Gas Content, ppm H_2 O_2 Control 55 850 Test 54 830	
21.1.44	Vantrol 31-130A (Vantrol Corp.)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	No surface effect	A
		Material Class Marking, Electrochemical, Cleaner				
22.1.1	Neutracleaner No. 1 (Electro Chem Etch Co.)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	SCC, Level 1	X
22.1.2	2-1 (Electromark Co.)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	SCC, Level 1	X
22.1.3	2-2 (Electromark Co.)	Single U-Bend	6-4 I	1000°F, 4 Hrs	SCC, Level 1	X
22.1.4	5 (Marking Methods, Inc.)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	SCC, Level 3	X
22.1.5	APC (Marking Methods, Inc.)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	SCC, Level 2	X

TABLE 4.–COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Marking, Electrochemical, Cleaner				
22.1.6	MSC No. 3 (Monode, Inc.)	Single U-Bend	6-4 I	$1000^{\circ}F$, 4 Hrs.	SCC, Level 2	X
22.1.7	MSC No. 5 (Monode, Inc.)	Single U-Bend	6-4 I	$1000^{\circ}F$, 4 Hrs.	SCC, Level 1	X
		Material Class Marking, Electrochemical, Electrolyte				
22.2.1	359L (Electro Chem Etch Co.)	Single U-Bend	6-4 I	$1000^{\circ}F$, 4 Hrs.	SCC, Level 1	X
22.2.2	E S and T (Electro Chem Etch Co.)	Single U-Bend	6-4 I	$1000^{\circ}F$, 4 Hrs.	Slight etch, Level 0	A
22.2.3	1 (Electromark Corp.)	Single U-Bend	6-4 I	$1000^{\circ}F$, 4 Hrs.	SCC, Level 4	X
22.2.4	2 (Electromark Corp.)	Single U-Bend	6-4 I	$1000^{\circ}F$, 4 Hrs.	SCC, Level 4	X
22.2.5	4 (Electromark Corp.)	Single U-Bend	6-4 I	$1000^{\circ}F$, 4 Hrs.	SCC, Level 5	X
22.2.6	59-L (Electromark Corp.)	Single U-Bend	6-4 I	$1000^{\circ}F$, 4 Hrs.	No surface effect	A
22.2.7	353 (Electromark Corp.)	Single U-Bend	6-4 I	$1000^{\circ}F$, 4 Hrs.	Etch, Level 0	X
22.2.8	SC-44 (Electromark Corp.)	Single U-Bend	6-4 I	$1000^{\circ}F$, 4 Hrs.	SCC, Level 1	X
22.2.9	SC-82 (Electromark Corp.)	Single U-Bend	6-4 I	$1000^{\circ}F$, 4 Hrs.	SCC, Level 1	X
22.2.10	T-10 (Marking Methods, Inc.)	Single U-Bend	6-4 I	$1000^{\circ}F$, 4 Hrs.	SCC, Level 1	X
22.2.11	B-10 (Monode, Inc.)	Single U-Bend	6-4 I	$1000^{\circ}F$, 4 Hrs.	SCC, Level 1	X

TABLE 4.—COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Marking, Electrochemical, Electrolyte				
22.2.12	F-10 (Monode, Inc.)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	SCC, Level 4	X
22.2.13	F-20 (Monode, Inc.)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	SCC, Level 1	X
		Material Class Marking, Temporary, Heat Treat Indicator				
23.1.1	"1150 F" (Tempilstik Co.)	Single U-Bend Single U-Bend	6-4 I 6-4 I	1000°F, 4 Hrs. 1150°F, 4 Hrs.	No surface effect No surface effect	A A
23.1.2	"1350 F" (Tempilstik Co.)	Single U-Bend Single U-Bend	6-4 I 6-4 I	1000°F, 4 Hrs. 1350°F, 4 Hrs.	Surface Roughened Surface Roughened	X X
		Material Class Marking, Temporary, Ink				
23.2.1	1107 NH (Dickson Ink Co.)	Double U-Bend	6-4	1000°F, 4 Hrs.	No surface effect	A
23.2.2	1307 (Dickson Ink Co.)	Single U-Bend	6-4	1000°F, 4 Hrs.	No surface effect	A
23.2.3	2101 (Dickson Ink Co.)	Single U-Bend	6-4	1000°F, 4 Hrs.	No surface effect	A
23.2.4	2307 (Dickson Ink Co.)	Single U-Bend	6-4	1000°F, 4 Hrs.	No surface effect	A
23.2.5	5507 (Dickson Ink Co.)	Single U-Bend	6-4	1000°F, 4 Hrs.	No surface effect	A
23.2.6	Type A Red Translucent (Magic Marker Corp.)	Chlorine		Beilstein	No detectible chlorine	A

TABLE 4.-- COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Marking, Temporary, Ink				
23.2.6 (cont'd)		IR Analysis			Solvent system: 99% xylene	
		U-Bend	8-1-1 I (uncleaned)	75°F, 24 Hrs.	No surface effect	
			6-4 I	1000°F, 4 Hrs.	No SCC or surface effect	
			8-1-1 I	1000°F, 4 Hrs.	No SCC or surface effect	
23.2.7	1001 Red (Pannier Ink Corp.)					X
		Chloride		Radiotracer Silver	6500 ppm chloride	
		IR Analysis			Solvent system: 40% ethanol, 16% ethoxy-ethanol, no chlorinated solvents	
		U-Bend	6-4 I	1000°F, 4 Hrs.	Severe surface pits and SCC	
23.2.8	Type A Red (Speedry Chemical Products Co.)	Double U-Bend	6-4 I	1000°F, 4 Hrs.	No surface effect	A
23.2.9	Ink (Esterbrook Co.)	Single U-Bend	6-4 I	1000°, 4 Hrs. Black, brown, blue, green, orange, purple, yellow tested	Either no SCC or surface effect, or very slight surface roughening (purple)	A
23.2.10	M-3 (Marsh Co.)			1000°F, 4 Hrs. Black, blue, orange tested	No SCC or surface effect	A
23.2.11	Project-A-Mark (Marsh Co.)			1000°F, 4 Hrs. Black, brown, blue, green, orange, purple, yellow tested	Slight surface roughening or no SCC or surface effect (blue, purple)	A
23.2.12	Ink (Sharpie Co.)			1000°F, 4 Hrs. Orange, purple, yellow tested	No SCC or surface effect	A

TABLE 4.–COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Marking, Temporary, Pencil				
23.3.1	551 Blue (Blaisdell Co.)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	No surface effect	A
		Material Class Metal				
24.1.1	Kirksite	Double U-Bend	6-4 I	<700°F, 168 Hrs.	No surface effect	A
		Double U-Bend	6-4 I	>717°F, minimum time not determined	Severe surface etch	X
24.1.2	Lead	Double U-Bend	6-4 I	500°F, 100 Hrs.	No surface effect	A
		Double U-Bend	6-4 I	1000°F, 4 Hrs.	Etch only	A (?)
		Double U-Bend	6-4 I	1650°F, 2 Hrs.	Massive surface effect	X
24.1.3	Mercury	Single U-Bend	6-4 I	75°F, 69 Hrs.	No surface effect	A
		Single U-Bend	6-4 I	320°F, 20 Min. titanium heated to 1000°F, 45 Min. prior to stressing	SCC, Level 5	X
		Material Class Paint, Leak Detector				
25.1.1	Orange Detector Paint (Fuller Co.)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	No surface effect	A
25.1.2	Kelite No. 9 (Kelite Chem Co.)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	Slight surface effect	A
25.1.3	Snoop No. 3 (Nupro Co.)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	No surface effect	A
25.1.4	Turco 520 (Turco Products, Inc.)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	No surface effect	A

TABLE 4.--COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Paint, Protective				
25.2.1	Epoxy Primer, Type I (BMS 10-11)					A
		Single U-Bend	6-4 I	450°F, 168 Hrs.	No SCC or surface effect	
		Single U-Bend	6-4 I	600°F, 168 Hrs.	No SCC or surface effect	
		Single U-Bend	6-4 I	1000°F, 4 Hrs.	Slight surface etch only	
25.2.2	Epoxy Enamel (BMS 10-11)					A
		Single U-Bend	6-4 I	450°F, 168 Hrs.	No SCC or surface effect	
		Single U-Bend	6-4 I	600°F, 168 Hrs.	Slight surface etch only	
		Single U-Bend	6-4 I	1000°F, 4 Hrs.	No SCC or surface effect	
25.2.3	Polyurethane Enamel (BMS 10-11)					A
		Single U-Bend	6-4 I	450°F, 168 Hrs.	No SCC or surface effect	
		Single U-Bend	6-4 I	600°F, 168 Hrs.	No SCC or surface effect	
		Single U-Bend	6-4 I	1000°F, 4 Hrs.	No SCC or surface effect	
		Material Class Penetrant Inspection Fluid, Developer				
26.1.1	9-D-3 (Androx, Australia PTY, Ltd)	Single U-Bend	6-4 I	1000°F, 4 Hrs, Dry Powder	No surface effect	A
		Single U-Bend	6-4 I	1000°F, 4 Hrs. Water slurry	Slight etch at material-titanium interface	A
26.1.2	DD-2 (Fluro-Chek Co.)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	Pitting	X
26.1.3	WD (Fluro-Chek Co.)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	Severe etching and pitting	X

TABLE 4.--COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Penetrant Inspection Fluid, Developer				
26.1.4	ZP-4 (Magnaflux Co.)	Chloride Single U-Bend	6-4 I	Bomb method 1000°F, 4 Hrs.	167 ppm Cl Slight surface etch	X
26.1.5	ZP-4A	Single U-Bend	6-4 I	1000°F, 4 Hrs.	No surface effect	A
26.1.6	ZP-5 (Magnaflux Corp.)	Chloride U-Bend	6-4 I	Bomb method 1000°F, 4 Hrs.	194 ppm Cl Slight surface etch	X
26.1.7	ZP-9 (Magnaflux Corp.)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	Slight etch, Level 0	A
26.1.8	ZP-11 (Magnaflux Corp.)	Chloride U-Bend	6-4 I	Bomb method 1000°F, 4 Hrs.	298 ppm Cl Slight surface etch	X
26.1.9	ZP-20 (Magnaflux Corp.)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	No surface effect	A
26.1.10	ZP-X-432 (ZP-13) (Magnaflux Corp.)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	SCC, Level No. 1	X
26.1.11	D-70 (Met-L-Chek Co.)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	No surface effects	A
26.1.12	D-492-B (Shannon Luminous Materials Co.)	U-Bend	8-1-1 I	1000°F, 4 Hrs.	Severe surface etch	X
26.1.13	D-492-C (Shannon)	Chloride U-Bend	8-1-1 I	Bomb method 1000°F, 4 Hrs.	5 ppm Cl Mild surface spots and etch	X
26.1.14	D 493 (Shannon)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	Very slight etch, Level 0	A

TABLE 4.—COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Penetrant Inspection Fluid Developer				
26.1.15	D-493A (Shannon)	Chloride U-Bend	8-1-1 I	Bomb method 1000°F, 4 Hrs.	283 ppm Cl No SCC or surface effect	A
26.1.16	D-495A (Shannon)	Chloride U-Bend	8-1-1 I	Bomb method 1000°F, 4 Hrs.	123 ppm Cl No SCC or surface effect	A
26.1.17	D-499B (Shannon)	Single U-Bend	6-4	1000°F, 4 Hrs.	Roughened surface	X
26.1.18	D-499C (Shannon)	Single U-Bend	6-4	1000°F, 4 Hrs	No surface effect	A
26.1.19	D-90 (Sherwin, Inc.)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	No surface effect	A
26.1.20	D-100 (Sherwin, Inc.)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	No surface effect	A
26.1.21	D-110 (Sherwin, Inc.)	Single U-Bend	8-1-1	1000°F, 4 Hrs.	Severe etch	X
26.1.22	D-113A (Sherwin, Inc.)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	Rough etching and pitting. Retest gave SCC, Level 2	X
26.1.23	L-028 (Sherwin, Inc.)	Single U Bend	6-4 I	1000°F, 4 Hrs.	No surface effect	A
26.1.24	DD-535 (Sperry Div., Automated Ind., Inc.)	Chloride U-Bend	8-1-1 I	Bomb method 1000°F, 4 Hrs.	103 ppm Cl No SCC or surface effect	A
26.1.25	DW-530 (Sperry Div.)	U-Bend	8-1-1 I	1000°F, 4 Hrs.	Slight surface etch	X
26.1.26	FS-33 (Testing Systems, Inc.)	Chloride U-Bend	8-1-1 I	1000°F, 4 Hrs.	200 ppm Cl Slight surface etch	X

TABLE 4.–COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Penetrant Inspection Fluid, Developer				
26.1.27	Fluoro Finder Dry (Testing Systems, Inc.)	U-Bend	8-1-1 I	1000°F, 4 Hrs.	SCC	X
26.1.28	Fluoro Finder Wet (Testing Systems, Inc.)	U-Bend	8-1-1 I	1000°F, 4 Hrs.	Slight SCC	X
26.1.29	Dy-Chek (Turco Products, Inc.)					A
		Chloride		Bomb method	26 ppm Cl	
		Resin Kettle	4-3-1 I	850°F, 8 Hrs.	No SCC or surface effect	
		Resin Kettle	6-4 I	850°F, 8 Hrs.	No SCC or surface effect	
		Resin Kettle	8-1-1 I	850°F, 8 Hrs.	No SCC or surface effect	
26.1.30	Nad Developer (Turco Products)					A
		Chloride		Bomb method	140 ppm Cl	
		U-Bend	8-1-1 I	1000°F, 4 Hrs.	No SCC or surface effect	
		Material Class Penetrant Inspection Fluid, Emulsifier/Remover				
26.2.1	9 PR-4 (Ardrox Australia PTY, Ltd.)	Single U-Bend	6-4 I	1000°F, 4 Hrs. 5% water solution of material	No surface effect	A
		Single U-Bend	6-4 I	1000°F, 4 Hrs. 20% water solution	No surface effect	A
26.2.2	ZE-3 (Magnaflux)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	No surface effect	A
26.2.3	ZE-4 (Magnaflux)					A
		Chloride		Bomb method	176 ppm Cl	
		U-Bend	8-1-1 I	1000°F, 4 Hrs.	No SCC or surface effect	
		Resin Kettle	4-3-1 I	850°F, 8 Hrs.	No SCC or surface effect	
		Resin Kettle	6-4 I	850°F, 8 Hrs.	No SCC or surface effect	
		Resin Kettle	8-1-1 I	850°F, 8 Hrs.	No SCC or surface effect	

TABLE 4.–COMPATIBILITY DATA, MANUFACTURING AID MATERIALS *(continued)*

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Penetrant Inspection Fluid, Emulsifier/Remover				
26.2.4	ZE-4A (Magnaflux)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	No surface effect	A
26.2.5	ZE-4B (Magnaflux)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	No surface effect	A
26.2.6	ZE-6(ZR-1) (Magnaflux)					A (?)
		Chloride		Bomb method, Batch "X"	119 ppm Cl	
		U-Bend	6-4 I	1000°F, 4 Hrs. Batch "X" 5% solution in c.w.	Pits and surface etch	
			6-4 I	1000°F, 4 Hrs. Batch "Y", 5% solution in c.w.	No SCC or surface effect	
26.2.7	ZR-2 (Same as ZE-6 plus antirust) (Magnaflux)					X
		Chloride		Bomb method	51 ppm Cl	
		U-Bend	6-4 I	1000°F, 4 Hrs. 5% solution in c.w.	Severe SCC	
			8-1-1 I	1000°F, 4 Hrs. 5% solution in distilled water	SCC and pits	
26.2.8	E-56 (Met-L-Chek Co.)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	No surface effect	A
26.2.9	E-59 (Met-L-Chek Co.)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	No surface effect	A
26.2.10	E-142 (Shannon Luminous Materials Co.)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	SCC, Level 1	X
26.2.11	E-153 (Shannon)					X
		Chloride		Bomb method	384 ppm Cl	
		U-Bend	8-1-1 I	1000°F, 4 Hrs.	Slight surface etch	
26.2.12	E-157A (Shannon)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	No surface etch	A
26.2.13	ER-82 (Sherwin, Inc.)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	Very slight etch, Level 0	A

TABLE 4.–COMPATIBILITY DATA, MANUFACTURING AID MATERIALS *(continued)*

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Penetrant Inspection Fluid, Emulsifier/Remover				
26.2.14	PE-520 (Sperry Div., Automated Ind., Inc.)	U-Bend	8-1-1	1000°F, 4 Hrs.	No SCC or surface etch	A
26.2.15	Dy-Chek (Turco Products, Inc.)					A
		Chloride		Bomb method	422 ppm Cl	
		Resin Kettle	4-3-1	850°F, 8 Hrs.	No SCC or surface etch	
		Resin Kettle	6-4	850°F, 8 Hrs.	No SCC or surface etch	
		Resin Kettle	8-1-1	850°F, 8 Hrs.	No SCC or surface etch	
26.2.16	E (Turco Products)	Single U-Bend	6-4	1000°F, 4 Hrs.	No surface effect	A
		Material Class Penetrant Inspection Fluid, Penetrant				
26.3.1	985-P2 (Ardrox Australia PTY, Ltd.)	Single U-Bend	6-4	1000°F, 4 Hrs.	No surface effect	A
26.3.2	ZL-2 (Magnaflux)					A
		Chloride		Bomb method	59 ppm Cl	
		U-Bend	6-4	1000°F, 4 Hrs.	No SCC or surface effect	
		Resin Kettle	4-3-1	850°F, 8 Hrs.	No SCC or surface effect	
		Resin Kettle	6-4	850°F, 8 Hrs.	No SCC or surface effect	
		Resin Kettle	8-1-1	850°F, 8 Hrs.	No SCC or surface effect	
26.3.3	ZL-2A (Magnaflux)					A
		Chloride		Bomb method	75 ppm Cl	
		U-Bend	6-4	1000°F, 4 Hrs.	No SCC or surface effect	
26.3.4	ZL-16 (Magnaflux)	Single U-Bend	6-4	1000°F, 4 Hrs.	No surface effect	A
26.3.5	ZL-17 (Magnaflux)					A
		Chloride		Bomb method	67 ppm Cl	
		U-Bend	6-4	1000°F, 4 Hrs.	No SCC or surface effect	

TABLE 4.–COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Penetrant Inspection Fluid, Penetrant				
26.3.6	ZL-17A (Magnaflux)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	No surface effect	A
26.3.7	ZL-18 (Magnaflux)	Chloride U-Bend	 6-4 I	Bomb method 700°F, 3 Hrs. plus 1000°F, 4 Hrs.	730 ppm Cl No SCC or surface effect	A
26.3.8	ZL-22 (Magnaflux)	Chloride U-Bend Resin Kettle Resin Kettle Resin Kettle	 6-4 I 4-3-1 I 6-4 I 8-1-1 I	Bomb method 1000°F, 4 Hrs. 850°F, 8 Hrs. 850°F, 8 Hrs. 850°F, 8 Hrs.	77 ppm Cl No SCC or surface effect No SCC or surface effect No SCC or surface effect No SCC or surface effect	A
26.3.9	ZL-22A (Magnaflux)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	No surface effect	A
26.3.10	ZL-22I (Magnaflux)	Chloride U-Bend	 6-4 I	Bomb method 1000°F, 4 Hrs.	73 ppm Cl No SCC or surface effect	A
26.3.11	ZL-30 (Magnaflux)	Chloride U-Bend	 6-4 I	Bomb method 700°F, 3 Hrs. plus 1000°F, 4 Hrs.	105 ppm Cl No SCC or surface effect	A
26.3.12	ZL-30A (Magnaflux)	Chloride U-Bend	 6-4 I	Bomb method 700°F, 3 Hrs. plus 1000°F, 4 Hrs.	96 ppm Cl No SCC or surface effect	A
26.3.13	FP-90 (Met-L-Chek)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	Very slight surface effect	A
26.3.14	FP-91 (Met-L-Chek)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	No surface effect	A

TABLE 4.–COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Penetrant Inspection Fluid, Penetrant				
26.3.15	FP-92 (Met-L-Chek)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	Slight surface effect	A
26.3.16	FP-93 (Met-L-Chek)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	Slight edge etch	A
26.3.17	FP-95 (Met-L-Chek)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	Slight edge etch	A
26.3.18	P3F (NAA-Rockwell)	U-Bend	6-4 I	1000°F, 4 Hrs.	No SCC or surface effect	A
26.3.19	P3F-3 (NAA-Rockwell)	U-Bend	6-4 I	1000°F, 4 Hrs.	No SCC or surface effect	A
26.3.20	P5F-1 (NAA-Rockwell)	U-Bend	6-4 I	1000°F, 4 Hrs.	No SCC or surface effect	A
26.3.21	P5F-2.5 (NAA-Rockwell)	U-Bend	6-4 I	1000°F, 4 Hrs.	No SCC or surface effect	A
26.3.22	P5F-3 (NAA-Rockwell)	U-Bend	6-4 I	1000°F, 4 Hrs.	Slight etch effect	A
26.3.23	P-133 (Shannon)	Chloride U-Bend U-Bend	 6-4 I 8-1-1 I	Bomb method 1000°F, 4 Hrs. 1000°F, 4 Hrs.	80 ppm Cl No SCC or surface effect No SCC or surface effect	A
26.3.24	P-133A (Shannon)	Double U-Bend	6-4 I	1000°F, 4 Hrs.	No surface effect	A
26.3.25	P-134 (Shannon)	Chloride U-Bend	 6-4 I	Bomb method 700°F, 3 Hrs. plus 1000°F, 4 Hrs.	148 ppm Cl No SCC or surface effect	A
26.3.26	P-134A	Double U-Bend	6-4 I	1000°F, 4 Hrs.	No surface effect	A
26.3.27	P-135 (Shannon)	Chloride U-Bend	 6-4 I	Bomb method 700°F, 3 Hrs. plus 1000°F, 4 Hrs.	148 ppm Cl No SCC or surface effect	A

TABLE 4.--COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Penetrant Inspection Fluid, Penetrant				
26.3.28	P 148A (Shannon)	Chloride U-Bend	6-4 I	Bomb method 700°F, 3 Hrs. plus 1000°F, 4 Hrs.	65 ppm Cl No SCC or surface effect	A
26.3.29	P 149 (Shannon)	Chloride U-Bend	6-4 I	Bomb method 700°F, 3 Hrs. plus 1000°F, 4 Hrs.	1% Cl No SCC or surface effect	A
26.3.30	P 150 (Shannon)	Chloride U-Bend	6-4 I	Bomb method 700°F, 3 Hrs. plus 1000°F, 4 Hrs.	1% Cl No SCC or surface effect	A
26.3.31	FP-22 (Sherwin, Inc.)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	No SCC or surface effect	A
26.3.32	HM-3 (Sherwin, Inc.)	Chloride U-Bend	6-4 I	Bomb method 1000°F, 4 Hrs.	44 ppm Cl No SCC or surface effect	A
26.3.33	HM-225 (Sherwin, Inc.)	U-Bend	6-4 I	1000°F, 4 Hrs.	No SCC or surface effect	A
26.3.34	HM-405 (Sherwin, Inc.)	U-Bend	6-4 I	1000°F, 4 Hrs.	No SCC or surface effect	A
26.3.35	FPE 505 (Sperry Div., Automated Ind., Inc.)	Chloride U-Bend	6-4 I	Bomb method 1000°F, 4 Hrs.	55 ppm Cl No SCC or surface effect	A
26.3.36	FL-50	Chloride U-Bend	6-4 I	Bomb method 700°F, 3 Hrs. plus 1000°F, 4 Hrs.	55 ppm Cl No SCC or surface effect	A

TABLE 4.—COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Penetrant Inspection Fluid, Penetrant				
26.3.37	Dy-Chek (Turco Products)					A
		Chloride		Bomb method	236 ppm Cl	
		Resin Kettle	4-3-1 I	850°F, 8 Hrs.	No SCC or surface effect	
		Resin Kettle	6-4 I	850°F, 8 Hrs.	No SCC or surface effect	
		Resin Kettle	8-1-1 I	850°F, 8 Hrs.	No SCC or surface effect	
26.3.38	P-40 (Turco Products)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	No surface effect	A
26.3.39	WP-1 (Turco Products)					A
		Chloride		Bomb method	53 ppm Cl	
		U-Bend	6-4 I	700°F, 3 Hrs. plus 1000°F, 4 Hrs.	No SCC or surface effect	
26.3.40	WP-167 (Turco Products)					A
		Chloride		Bomb method	78 ppm Cl	
		U-Bend	6-4 I	700°F, 3 Hrs. plus 1000°F, 4 Hrs.	No SCC or surface effect	
26.3.41	WP-167R (Turco Products)	U-Bend	6-4 I	1000°F, 4 Hrs.	No surface effect	A
		Material Class Protective Coating, Heat Treat				
27.1.1	Delta 31 (Acheson Colloids Co.)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	Etch, Level 0	A
27.1.2	FH-420 (Acheson)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	No surface effect	A
27.1.3	WK-308X (Acheson)	Single U-Bend	6-4 I	1000°F, 4 Hrs.	No surface effect	A
27.1.4	Boric Acid	Single U-Bend	6-4 I	1000°F, 4 Hrs.	No surface effect	A
		Single U-Bend	6-4 I	1450°F, 1 Hr. Solution dried on specimen	No surface effect	A

TABLE 4.–COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Protective Coating, Heat Treat				
27.1.5	Boric Acid plus General Electric SR350 silicone binder in methyl ethyl ketone	Single U-Bend	6-4 I	1450°F, 1 Hr.	No surface effect	A
27.1.6	Kalcote XP (California Coatings Co.)					A
		Flat Sheet Exposure	6-4 I	1000°F, 4 Hrs. single specimen	No visible surface effect after descaling	
		Flat Sheet Exposure	6-4 I	1350°F, 30 Min. single specimen	No visible surface effect after descaling	
		Flat Sheet Exposure	6-4 I	1725°F, 10 Min. single specimen	No visible surface effect after descaling	
		Allison Bend	6-4 I	1000°F, 4 Hrs.	Bend Energy, in-lbs Control 100 Test 83	
		Allison Bend	6-4 I	1350°F, 30 Min.	Control 109 Test 98	
		Allison Bend	6-4 I	1725°F, 10 Min.	Control 28 Test 30	
21.1.7	Kalube FL-40 (Kalgard FL-40) (California Coatings Co.)					A
		Chloride		Bosler method	Negative (Qualitative only)	
		Flat Sheet Exposure	6-4 I 6-4 I 6-4 I 6-4 I	1000°F, 4 Hrs. 1350°F, 30 Min. 1725°F, 10 Min. 1900°F, 10 Min.	No visible surface effect after descaling	

TABLE 4.--COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Protective Coating, Heat Treat				
27.1.7 (cont'd)		Allison Bend		1000°F, 4 Hrs.	Bend Energy, In-lbs Control 100 Test 97	
				1350°F, 30 Min.	Control 109 Test 96	
				1725°F, 10 Min.	Control 28 Test 26	
				1900°F, 10 Min.	Control 7 Test 10	
27.1.8	Kalube FL (Kalgard FL) (California Coating Co.)					A
		Chloride Flat Sheet Exposure		Bosler method	Negative (Qual. only)	
			6-4 I 6-4 I 6-4 I 6-4 I	1000°F, 4 Hrs. 1350°F, 30 Min 1725°F, 10 Min. 1900°F, 10 Min	No visible surface effects after descaling	
		Allison Bend	6-4 I	1000°F, 4 Hrs.	Bend Energy, In-lbs Control 100 Test 95	
		Allison Bend	6-4 I	1350°F, 30 Min.	Control 109 Test 113	
		Allison Bend	6-4 I	1725°F, 10 Min.	Control 28 Test 50	
		Allison Bend	6-4 I	1900°F, 10 Min.	Control 7 Test 9	

TABLE 4.–COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations			Compatibility Rating
		Material Class Protective Coating, Heat Treat						
					Temp, °F	Metal Removed	Emittance	
						Mils per side		
27.1.8 (cont'd)		Emittance	6-4 I	Flat sheet exposure specimens as above. Surface removed by chemical milling per BAC 5842 as indicated	1000	0.0	0.15	
						1.2	0.15	
						1.9	0.15	
					1350	0.0	0.15	
						1.1	0.15	
						1.9	0.15	
					1725	0.0	0.19	
						0.8	0.18	
						1.9	0.175	
					1900	0.0	0.22	
						1.4	0.20	
						2.3	0.18	
27.1.9	T-50 (Everlube Corp. of America)							A
		Flat Sheet Exposure	6-4 I 6-4 I 6-4 I 6-4 I	1000°F, 4 Hrs. 1350°F, 30 Min. 1725°F, 10 Min. 1900°F, 10 Min.	No visible surface effect after descaling			
		Allison Bend	6-4 I	1000°F, 4 Hrs.	Bend Energy, In-lbs Control 100 Test 104			
			6-4 I	1350°F, 30 Min.	Control 109 Test 107			
			6-4 I	1725°F, 10 Min.	Control 28 Test 26			

TABLE 4.–COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations			Compatibility Rating
		Material Class Protective Coating, Heat Treat			Bend Energy, In-lbs.			
27.1.9 (cont'd)		Allison Bend	6-4 I	1900°F, 10 Min.	Control 7 Test 10			
		Emittance		Flat sheet exposure specimens as above. Surface removed by chemical milling per BAC 5842 as indicated	Temp °F	Metal Removed	Emittance	
						Mils per side		
					1000	0.0	0.16	
						1.1	0.15	
						2.0	0.15	
					1350	0.0	0.15	
						0.9	0.15	
						2.0	0.15	
					1725	0.0	0.19	
						1.8	0.155	
					1900	0.0	0.20	
						1.8	0.185	
27.1.10	C-300 (Fel-Pro., Inc.)							A
		Chloride		Bosler method	Negative			
		Flat Sheet Exposure	6-4 I	1100°F, 30 Min.	No visible surface effect after descaling			
			8-1-1 I	1100°F, 30 Min.	No visible surface effect after descaling			
		Allison Bend	6-4 I	1100°F, 30 Min.	Bend Energy, In-lbs Control 59 Test 48			
			8-1-1 I	1100°F, 30 Min.	Control 26 Test 23			

TABLE 4.–COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Protective Coating, Heat Treat				
27.1.10 (cont'd)		Gas Analysis	6-4 I	Flat sheet exposure specimens	Gas Content, ppm H_2 O_2 Control 46 933 Test 57 1095	
			8-1-1 I	Flat sheet exposure specimens	Control 45 590 Test 53 643	
27.1.11	A-498 (Glidden-Metlseel)	Flat Sheet Exposure	6-4 I	1000°F, 4 Hrs. 1250°F, 4 Hrs. 1725°F, 30 Min. 1900°F, 30 Min.	Ceramic coating left after temperature exposure, not removable by nitric-fluoride etch	X
27.1.12	RA-536 (Glidden-Metlseel)	Flat Sheet Exposure	6-4 I	1000°F, 4 Hrs. 1250°F, 4 Hrs 1725°F, 30 Min. 1900°F, 30 Min.	Ceramic coating left after temperature exposure, not removable by nitric-fluoride etch	X
27.1.13	RA-537 (Glidden-Metlseel)	Flat Sheet Exposure	6-4 I	1000°F, 4 Hrs. 1250°F, 4 Hrs. 1725°F, 30 Min. 1900°F, 30 Min.	Ceramic coating left after temperature exposure, not removable by nitric fluoride etch	X
27.1.14	RA-536 (Glidden-Metlseel)	Flat Sheet Exposure	6-4 I	1000°F, 4 Hrs. 1250°F, 4 Hrs. 1725°F, 30 Min. 1900°F, 30 Min.	Ceramic coating left after temperature exposure, not removable by nitric-fluoride etch	X
27.1.15	HD 200 (Kerns Pacific Corp.)	U-Bend	8-1-1 I	1000°F, 4 Hrs.	Dull surface finish (characteristic of effect produced by not spraying material onto surface)	A (600°F max.)
27.1.16	HD205 (Kerns Pacific)					X
		Flat Sheet Exposure	6-4 I	1000°F, 4 Hrs.	Speckled surface	
		Flat Sheet Exposure	6-4 I	1250°F, 4 Hrs.	Badly speckled surface	

TABLE 4.–COMPATIBILITY DATA, MANUFACTURING AID MATERIALS *(continued)*

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Protective Coating, Heat Treat				
27.1.16 (cont'd)		Flat Sheet Exposure	6-4 I	1725°F, 30 Min.	Frost pattern on surface	
		Flat Sheet Exposure	6-4 I	1900°F, 30 Min.	Frost patteron on surface	
27.1.17	HD6330 (Kerns Pacific)	U-Bend	8-1-1 I	1000°F, 4 Hrs.	Dull surface finish (characteristic of effect produced by not spraying material onto surface)	A
27.1.18	LF22 (Lubri-Film, Inc.)					A
		U-Bend	6-4 I	1000°F, 4 Hrs.	Very slight dull surface finish	
			8-1-1 I	1000°F, 4 Hrs.	Very slight dull surface finish	
		Flat Sheet Exposure	6-4 I	1000°F, 4 Hrs, Brush application	Very slight dull surface finish	
			8-1-1 I	1000°F, 4 Hrs, Brush application	Very slight dull surface finish	
			6-4 I	1000°F, 4 Hrs, Dip coat application	No surface effect	
		Flat Sheet Exposure	6-4 I	1725°F, 10 Min.	Severe etch, with obvious brush marks	
			8-1-1 I	1725°F, 10 Min.	Severe etch, with obvious brush marks	
		Metal Removal	6-4 I and 8-1-1 I	Chemical milling according to BAC 5842	1 Mil/side to remove dull finish from 1000°F specimens. 2.5 Mil/side to remove etch from 1725°F specimens	
27.1.19	LF-32 (Lubri-Film, Inc.)	U-Bend	8-1-1 I	1000°F, 4 Hrs.	Dull surface finish	A (600°F max.)

TABLE 4.–COMPABILITY DATA, MANUFACTURING AID MATERIALS (continued)

No. Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Protective Coating, Heat Treat				
27.1.20	LF-70 (Lubri-Film, Inc.)	Single U-Bend	6-4 I	1450°F, 1.5 Hrs.	Did not clean up	X
27.1.21	LF-75 (Lubri-Film, Inc.)	Single U-Bend	6-4 I	1450°F, 1.5 Hrs.	Did not clean up	X
27.1.22	LF-80 (Lubri-Film, Inc.)	Single U-Bend	6-4 I	1450°F, 1.5 Hrs.	Did not clean up	X
27.1.23	LF-500 (Lubri-Film, Inc.)	U-Bend	8-1-1 I	1000°F, 4 Hrs.	Very slight dull surface effect	A (600°F max.)
27.1.24	LF-600 (Lubri-Film, Inc.)	U-Bend	8-1-1 I	1000°F, 4 Hrs.	Dull surface finish	A (600°F max.)
27.1.25	LF-700 (Lubri-Film, Inc.)	U-Bend	8-1-1 I	1000°F, 4 Hrs.	Very slight dull surface finish	A (600°F max.)
27.1.26	379-40C (Gold) (Turco Products)	Single U-Bend	6-4 I	1450°F, 1.5 Hrs.	No surface effect	A
27.1.27	379-40D (Red) (Turco Products)	Single U-Bend	6-4 I	1450°F, 1.5 Hrs.	No surface effect	A
27.1.28	Turco Pretreat (Turco Products)					A
		Flat Sheet Exposure	6-4 I	1000°F, 4 Hrs.	No visible surface effect after descaling	
			6-4 I	1350°F, 30 Min.	No visible surface effect after descaling	
			6-4 I	1725°F, 10 Min.	No visible surface effect after descaling	
			6-4 I	1900°F, 10 Min.	No visible surface effect after descaling	
		Allison Bend		1000°F, 4 Hrs.	Bend Energy, In-lbs Control 100 Test 104	
				1350°F, [illegible]	Control 109 Test 107	

TABLE 4.—COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations			Compatibility Rating
		Material Class Protective Coating, Heat Treat						
27.1.28 (cont'd)				1725°F, 10 Min.	Control 28			
					Test 26			
				1900°F, 10 Min.	Control 7			
					Test 10			
		Emittance	6-4 I	Flat sheet exposure specimens as above. Surface layer removed by chemical milling per BAC 5842 as indicated	Temp, °F	Metal Removed	Emittance	
						Mils per side		
					1000	0.0	0.15	
						1.5	0.15	
						3.2	0.15	
					1350	0.0	0.15	
						2.3	0.15	
						3.9	0.15	
					1725	0.0	0.18	
						1.0	0.165	
						2.1	0.15	
					1900	0.0	0.21	
						0.8	0.20	
						2.0	0.165	
						2.6	0.15	
27.1.29	Covington Cote (Timet Corp.)	Flat Sheet Exposure	6-4 I	1000°F, 4 Hrs.	No surface effect			X
				1250°F, 4 Hrs.	Frost pattern			
				1725°F, 30 Min.	Specimen warped			
				1900°F, 30 Min.	Specimen warped			

TABLE 4.--COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Protective Coating, Heat Treat				
27.1.30	Gage Cote 6					A
		Single U-Bend	6-4 I	500°F, 48 Hrs.	No surface effect	
		Single U-Bend	6-4 I	600°F, 48 Hrs.	No surface effect	
		Single U-Bend	6-4 I	700°F, 48 Hrs.	No surface effect	
		Single U-Bend	6-4 I	1000°F, 4 Hrs.	No surface effect	
		Material Class Protective Coating, Spinning Compound				
27.2.1	Warren No. 1 (Warren Chemical Manufacturing Co.)	U-Bend	8-1-1 I	1000°F, 4 Hrs.	SCC and pits	X
27.2.2	Warren No. 2 (Warren Chemical)	U-Bend	8-1-1 I	1000°F, 4 Hrs.	SCC and pits	X
		Material Class Protective Coating Temporary, Strippable				
27.3.1	Fuller 175-K-14 (W.P. Fuller Co.)					X
		Chloride		Company literature	Polyvinyl chloride base	
		Flat Sheet Exposure	6-4 I	550°F, 3 Hrs. Two heavy dip coats, dry between	No visible surface effect	
		Allison Bend	6-4 I	Specimens as above	Bend energy, In-lbs Control 67 Test 64	
		Resin Kettle	4-3-1 I	850°F, 3 Hrs. Two dip coats (dry between) plus one undried coat	No SCC or surface effect	
		Resin Kettle	6-4 I	850°F, 3 Hrs. Two dip coats (dry between) plus one undried coat	Specimen broke	

TABLE 4.–COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
	Material Class Protective Coating Temporary, Strippable					
27.3.1 (cont'd)		Resin Kettle	8-1-1 I	850°F, 3 Hrs, Two dip coats (dry between) plus one undried coat	Specimen broke	
27.3.2	1-1043 (Organocerams, Inc.)					A
		U-Bend	6-4 I	1000°F, 4 Hrs.	No SCC or surface effect	
		U-Bend	8-1-1 I	1000°F, 4 Hrs.	No SCC or surface effect	
27.3.3	1-1044 (Organocerams, Inc.)					A
		U-Bend	6-4 I	1000°F, 4 Hrs.	No SCC or surface effect	
		U-Bend	8-1-1 I	1000°F, 4 Hrs.	No SCC or surface effect	
27.3.4	1-2020 (Organocerams, Inc.)	U-Bend	6-4 I	450°F, 24 Hrs.	No SCC or surface effect	A
27.3.5	SC-277-2 (Spraylat Corp.)					A
		Chloride		Company literature	Polyvinyl chloride base	
		Flat Sheet Exposure	6-4 I	550°F, 3 Hrs. Two heavy coats, dry between	No visible surface effect	
		Allison Bend	6-4 I	Specimens from above	Bend Energy, In-lbs Control 67 Test 73	
		Resin Kettle-1	4-3-1 I	850°F, 4 Hrs. One dip coat, dry	No SCC or surface effect	
		Resin Kettle-1	6-4 I	850°F, 4 Hrs. One dip coat, dry	No SCC or surface effect	
		Resin Kettle-1	8-1-1 I	850°F, 4 Hrs. One dip coat, dry	No SCC or surface effect	

TABLE 4.–COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Protective Coating Temporary, Strippable				
27.3.5 (cont'd)		Resin Kettle-2	4-3-1 I	Specimen from Resin Kettle-1 test left in kettle, 35 ml of SC-277-2 added, and then heated at 850°F for 30 Min.	No SCC or surface effect	
		Resin Kettle-2	6-4 I	Specimen from Resin Kettle-1 test left in kettle, 35 ml of SC-277-2 added, and then heated at 850°F for 30 Min.	No SCC or surface effect	
		Resin Kettle-2	8-1-1 I	Specimen from Resin Kettle-1 test left in kettle, 35 ml of SC-277-2 added, and then heated at 850°F for 30 Min.	No SCC or surface effect	
27.3.6	SC-1071 (Spraylat Corp.)					A
		Flat Sheet Exposure	6-4 I	550°F, 3 Hrs. Two heavy dip coats, dry between		
		Allison Bend	6-4 I	Specimens from above flat sheet exposure	Bend Energy, In-lbs Control 67 Test 68	
		Resin Kettle	4-3-1 I	850°F, 4 Hrs. One dip coat (dry)	No SCC or surface effect	
		Resin Kettle	6-4 I	850°F, 4 Hrs. One dip coat (dry)	No SCC or surface effect	
		Resin Kettle	8-1-1 I	850°F, 4 Hrs. One dip cost (dry)	No SCC or surface effect	

TABLE 4.—COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Salt, Inorganic				
28.1.1	Silver Chloride (Paste)	U-Bend	6-4 I	1000°F, 4 Hrs.	SCC, Level 5	X
28.1.2	Silver iodide (Paste)	U-Bend	6-4 I	1000°F, 4 Hrs.	Severe dissolution	X
28.1.3	Silver nitrate (3.5% solution)	U-Bend	6-4 I	1000°F, 4 Hrs.	SCC, Level 1 to 2	X
28.1.4	Sodium chloride	U-Bend	6-4 I	1000°F, 4 Hrs. Solution of NaCl in distilled water*	Cl^- concentration ppm / Depth of SCC fracture, Mils: 5 / 1.8 10 / 5.2 20 / 5.6 40 / 21.3 See photomicrographs in Section 5.4	
		Material Class Scale Conditioner, Aqueous				
29.1.1	8224 (Brandt Chemical Co.)	Double U-Bend	6-4 I	265°F, 72 Hrs.	Slight surface polishing No pitting or etching Electron micrographs reveal no attack	A
29.1.2	Sodium hydroxide (50% solution)	Flat Sheet Exposure	6-4 I	270°F, 1 Hr.	Slight conversion coating	A (operating temperature of 270° - 290°F)

*The SCC effect of a given Cl^- concentration in distilled water is greater than that of the same Cl^- concentration in natural water, so that this is a worst-case exposure.

TABLE 4.–COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Scale Conditioner, Aqueous				
29.1.2 (cont'd)		Allison Bend	6-4 I	270°F, 1 Hr.	Bend Energy, In-lbs Control 104 Test 88	
		Allison Bend	6-4 I	270°F, 1 Hr. plus 4 Min. pickle per BAC 5753	Control 104 Test 104	
29.1.3	Turco 4316 (Turco Products, Inc.)					A (operating temperature 270° - 290°F)
		Flat Sheet Exposure	6-4 I	270°F, 1 Hr.	Slight conversion coating	
		Allison Bend	6-4 I	270°F, 1 Hr.	Bend Energy, In-lbs Control 105 Test 88	
			6-4 I	270°F, 1 Hr. plus 4 Min. pickle per BAC 5753	Control 105 Test 103	
29.1.4	Turco 4338 (Turco Products, Inc.)					A (operating temperature 190° - 210°F)
		Flat Sheet Exposure	6-4 I	195°F, 30 Min.	Slight conversion coating	
		Allison Bend	6-4 I	195°F, 30 Min.	Bend Energy, In-lbs Control 105 Test 77	
			6-4 I	195°F, 30 Min. plus 4 Min. pickle per BAC 5753	Control 105 Test 98	

TABLE 4.–COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters		Metal Loss Mils	H_2 Pick-up ppm	O_2 Pick-up ppm	Surface Roughness RHR	Compatibility Rating
		Material Class Scale Conditioner, Molton Salt								
29.2.1	Proprietary (Boeing Manu. Res.)	Flat Sheet Exposure	6-4 I	700°F	0.5 hr	0.0	2	–15	13	**A (Immersion time** limited to 2 - 5 minutes, with a 30 min. maximum cumulative)
			6-4 I	700°F	2 hr	0.5	18	115	12	
			6-4 I	700°F	24 hr	0.7	30	80	12	
29.2.2	Carus 303 (Carus Chem. Co. Inc.)	Flat Sheet Exposure	6-4 I (Heat G-7791)	500°F	0.5 hr	0.0	74	330	40	X
				500°F	2 hr	0.5	596	240	37	
				500°F	24 hr	3.0	3102	460	31	

TABLE 4.–COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters		Results-Observations				Compatibility Rating
		Material Class Scale Conditioner, Molton Salt								
29.2.3	Virgo (Hooker Chem. Co.)	Flat Sheet Exposure				Metal Loss Mils	H_2 Pick-up ppm	O_2 Pick-up ppm	Surface Rough-ness RHR	A (Immersion time limited to 2 - 5 minutes, with 30 minute cumulative maximum)
			6-4 I	850°F	0.5 hr	0.1	21	425	33	
			6-4 I	850°F	2 hr	0.8	32	327	93	
			6-4 I	850°F	24 hr	3.7	482	270	210	
29.2.4	DGS (Kolene Co.)	Flat Sheet Exposure				Metal Loss Mils	H_2 Pick-up ppm	O_2 Pick-up ppm	Surface Rough-ness RHR	A (Immersion time limited to 2 - 5 min. with 30 min. cumulative maxi-mum)
			6-4 I	850°F	0.5 hr	0.6	19	−30	80	
			6-4 I	850°F	2 hr	1.7	57	98	160	
			6-4 I	850°F	24 hr	14.8	293	20	>200	

TABLE 4.–COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
			Material Class Solvent			
30.1.1	Acetic Acid, Glacial				(See Vol. 1, ref 2 for additional data)	A (850°F max.)
		Resin Kettle	4-3-1 1	850°F, 8 Hrs.	No SCC or surface effect	
		Resin Kettle	6-4 I	850°F, 8 Hrs.	No SCC or surface effect	
		Resin Kettle	8-1-1 I	850°F, 8 Hrs.	No SCC or surface effect	
30.1.2	Ammonium Hydroxide (29% solution)					X
		Resin Kettle	4-3-1 I	450°F, 16 Hrs.	Slight surface effect	
		Resin Kettle	6-4 I	450°F, 16 Hrs.	Slight surface effect	
		Resin Kettle	8-1-1 I	450°F, 16 Hrs.	Slight surface effect	
30.1.3	Butyl alcohol					A (ambient temperature only)
		U-Bend	6-4, Timet Ht D8839 Comp. C Ann Type 3	75°F, 168 Hrs.	No SCC or surface effect	
		U-Bend	8-1-1, Ht D8141 Mill Anneal	75°F, 168 Hrs. specimens cleaned per BAC 5753 Method 2	No SCC or surface effect	
		U-Bend	8-1-1, Ht D8141 Mill Anneal	75°F, 168 Hrs, specimens cleaned as above and heated ½ hr at 1100°F	No SCC or surface effect	

TABLE 4.–COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
			Material Class Solvent			
30.1.4	Butyl Carbitol (Diethylene glycol monobutyl ether) (Union Carbide Corp.)					A (850°F max.)
		Resin Kettle	6-4 I	850°F, 2 Hrs.	No SCC or surface effect	
			8-1-1 I	850°F, 2 Hrs.	No SCC or surface effect	
		U-Bend	8-1-1 I, Timet, Ht D8141 Mill Anneal	75°F, 168 Hrs. Specimens cleaned per BAC 5753, method 2	No SCC or surface effect	
30.1.5	Butyl Cellosolve (Ethylene glycol monobutyl ether) (Union Carbide Corp.)				See 20.1.3, Lubricant/ Coolant	A
30.1.6	Carbon Tetrachloride					X (Prohibited for Boeing manu. use due to toxicity)
30.1.7	Ethanol, absolute	U-Bend	6-4, Timet Ht D8839 Comp C Ann, Type 3	75°F, 168 Hrs. Specimens cleaned per BAC 5753, method 2	1 specimen fractured (SCC) in 29 Hr. 2 specimens showed no SCC or surface effect	X

TABLE 4.--COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
			Material Class Solvent			
30.1.7 (cont'd)			8-1-1, Timet Ht D8141 Mill Anneal	75°F, 168 Hrs. Cleaned as above	1 specimen fractured (SCC) in 5 Hrs. 1 specimen in 75 Hrs. 1 specimen showed no SCC or surface effect	
			8-1-1, Timet Ht D8141 Mill Anneal	75°F, 168 Hrs. Tested in as received surface condition	No SCC or surface effect	
30.1.8	Ethylene Glycol	U-Bend	6-4, Timet Ht D8839 Comp C Ann Type 3	75°F, 168 Hrs. 6 specimens cleaned per BAC 5753, method 2	No SCC or surface effect	X
			8-1-1, Timet Ht D8141 Mill Anneal	As above 3 specimens	No SCC or surface effect	
			8-1-1, RMI Sht 504 Ht 30526 Spec MST	75°F, 168 Hrs. 5 specimens, as received plus 0.5 Hr. at 1100°F	No SCC or surface effect on 3 specimens. 1 specimen each fractured (SCC) in 0.5 and 20 Hrs.	
			8-1-1, GR470 Mill Anneal			

TABLE 4.--COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
			Material Class Solvent			
30.1.9	Freon 1301 (DuPont)	Heimerl-Braski	6-4 I	500°F, 0.25 Hr.	No surface effect. t = 1.1	A
30.1.10	Freon MF ($C\,Cl_3F$) (DuPont)					A
		U-Bend	6-4, Timet Ht D8839 Comp C Ann Type 3	75°F, 168 Hrs. 1 specimen, as received, plus notch across stressed area	No SCC or surface effect	
		U-Bend	8-1-1, Timet Ht D8141	75°F, 168 Hrs. 4 specimens, cleaned per BAC 5753, method 2	No SCC or surface effect	
		U-Bend	8-1-1, Timet Ht D8141	75°F, 168 Hrs. 2 specimens cleaned per BAC 5753, method 2 plus 0.5 Hr. at 1100°F	No SCC or surface effect	
30.1.11	Freon PCA ($C\,Cl_2F \cdot C\,ClF_2$)					A (500°F max.)
		Resin Kettle	4-3-1 I	500°F, 100 Hrs.	No SCC or surface effect	
		Resin Kettle	6-4 I	500°F, 100 Hrs.	No SCC or surface effect	
		Resin Kettle	8-1-1 I	500°F, 150 Hrs.	No SCC or surface effect	
		Resin Kettle	4-3-1 I	600°F, 25 Hrs, 4 specimens	No SCC or surface effect	
		Resin Kettle	6-4 I	600°F, 25 Hrs. 4 specimens	No SCC or surface effect	
		Resin Kettle	8-1-1 I	600°F, 25 Hrs. 4 specimens	3 specimens no SCC or surface effect 1 specimen fractured (SCC)	
		Resin Kettle	6-4 I	700°F, 17 Hrs. 4 specimens	No SCC or surface effect	

TABLE 4.—COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
			Material Class Solvent			
30.1.11 (cont'd)			8-1-1 I	700°F, 17 Hrs. 4 specimens	1 specimen no SCC or surface effect 3 specimens fractured (SCC)	
		Resin Kettle	4-3-1 I	850°F, 2 Hrs.	Fracture (SCC)	
		Resin Kettle	5-2.5 I	850°F, 2 Hrs.	Fracture (SCC)	
		Resin Kettle	6-4 I	850°F, 2 Hrs.	Fracture (SCC)	
		Resin Kettle	8-1-1 I	850°F, 2 Hrs.	Fracture (SCC)	
30.1.12	Hexane					A
		U-Bend	6-4, Timet Ht D8839 Comp C Ann Type 3	75°F, 168 Hrs. Specimens cleaned per BAC 5753, method 2	No SCC or surface effect	
			8-1-1, Timet Ht D8141	75°F, 168 Hrs. Cleaned per BAC 5753, method 2 plus 0.5 Hr. at 1100°F	No SCC or surface effect	
30.1.13	Methanol					X
		U-Bend	CP 75A Sht 1310 0.050" thick	75°F, 51-75 Hrs. Cleaned per BAC 5753, method 2, 3 specimens	Fracture (SCC)	
			4-3-1, Crucible, Ht P5946 Ann Type 3 0.050" gage	75°F, 3.1-17 Hrs. 7 specimens cleaned as above	Fracture (SCC)	

TABLE 4.–COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
			Material Class Solvent			
30.1.13 (cont'd)			5-2.5, Timet Sht S5652 D8832 0.050" gage	75°F, 1.6-6 Hrs. 6 specimens cleaned per BAC 5753, method 2	Fracture (SCC)	
			6-4 Timet ST A8364 0.040" gage	75°F, 4.5-16.5 Hrs. 4 specimens cleaned per BAC 5753, method 2	Fracture (SCC)	
			6-4 Timet STA A-8911 0.040" gage	75°F, 4 specimens standard cleaning	Fracture (SCC) average time = 15.8 Hrs.	
			8-1-1 Timet, Ht D8141 Mill Anneal 0.040" Gage	75°F, 22 specimens	Fracture (SCC) average time to fracture = 1.3 Hr.	
			6-4 Timet Ht D8839 Comp C Ann Type 3 0.040" gage	75°F, 11 specimens standard cleaning	Fracture (SCC) time to fracture 1.8-8.3 Hrs. average · 5.5 Hrs.	

TABLE 4. - COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
			Material Class Solvent			
30.1.13 (cont'd)			6-4 Timet Ht D8839 Comp C Ann Type 3 0.040" gage	75°F, specimens cleaned, bolted to producing varying angles between legs of U-bend, 1 specimen for each angle (See figure 2 for plot of data)	Included angle between legs, degrees — Hours to specimen fracture (SCC): 0° — 6 9° — 6.5 12° — 8 15° — 9 23° — 11 30° — 14.5 37° — 19 48° — 40 67° — > 168, no SCC or fracture	
30.1.14	Methyl Chloroform ($C\,Cl_3\,CH_3$)	Resin Kettle	6-4 I 8-1-1 I 6-4 I 8-1-1 I	700°F, 8 Hrs. 700°F, 8 Hrs. 850°F, 8 Hrs. 850°F, 8 Hrs.	No SCC or surface effect No SCC or surface effect Fracture (SCC) Fracture (SCC)	A (700°F max.)
30.1.15	Methyl Ethyl Ketone (MEK)	U-Bend	8-1-1 I, Timet Ht D8141 8-1-1 I, Timet Ht D8141	75°F, 168 Hrs. Specimens in as received condition 75°F, 168 Hrs. Specimens cleaned, plus 1100°F, 0.5 Hr.	No SCC or surface effect No SCC or surface effect	A (ambient temp. only)

TABLE 4.–COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
			Material Class Solvent			
30.1.16	Perchlorethylene ($Cl_2C\ C\ Cl_2$)	Resin Kettle	6-4 I	600°F, 6 Hrs.	No SCC or surface effect	A (600°F max.)
			8-1-1 I	600°F, 6 Hrs.	No SCC or surface effect	
			4-3-1 I	700°F, 2 Hrs.	1 specimen fractured (SCC) 1 specimen no SCC or surface effect	
			6-4 I	700°F, 2 Hrs. 3 specimens	No SCC or surface effect	
			6-4 I	700°F, 2 Hrs. 5 specimens (duplicate run)	5 specimens fractured (SCC)	
			8-1-1 I	700°F, 2 Hrs. 1 specimen	Fracture (SCC)	
30.1.17	n-Propyl Alcohol (Propanol)	U-Bend	8-1-1 I Timet Ht D8141	75°F, 168 Hrs. Standard cleaning	No SCC or surface effect	A (ambient temp. only)
			8-1-1 I Timet Ht D8141	75°F, 168 Hrs. Standard cleaning plus 1100°F, 0.5 Hr.	No SCC or surface effect	
30.1.18	iso-Propyl Alcohol (2-Propanol)	U-Bend	6-4 I Timet Ht D8839 Comp C Type 3	75°F, 168 Hrs. Standard cleaning	No SCC or surface effect	A (ambient temp. only)
			8-1-1 I Timet, Ht D8141	75°F, 168 Hrs. Standard	No SCC or surface effect	

TABLE 4.–COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
			Material Class Solvent			
30.1.19	Propylene Glycol (1, 2-Dihydroxy-propane)					A
		Heimerl-Braski	6-4 I	250°F, 65 Hrs. Immersed	t value not available but led to A rating (t < 3.71)	
		U-Bend	6-4 I	250°F, 65 Hrs. Immersed	No SCC or surface effect	
			8-1-1 I	350°F, 12 Hrs. Specimen continuously exposed to refluxed glycol	No SCC or surface effect	
		Resin Kettle	8-1-1 I	500°F, 11 Hrs.	No SCC or surface effect	
30.1.20	Trichlorethylene ($ClCH = C\ Cl_2$)					A (550°F max.)
		Resin Kettle	4-3-1 I	500°F, 100 Hrs.	No SCC or surface effect	
			6-4 I	500°F, 100 Hrs.	No SCC or surface effect	
			8-1-1 I	500°F, 100 Hrs.	No SCC or surface effect	
			4-3-1 I	600°F, 100 Hrs.	No SCC or surface effect	
			6-4 I	600°F, 100 Hrs.	No SCC or surface effect	
			8-1-1 I	600°F, 100 Hrs.	Fracture (SCC)	
			6-4 I	700°F, 1000 Hrs.	Fracture (SCC)	
			8-1-1 I	700°F, 1000 Hrs.	Fracture (SCC)	
			CP 75A	850°F, 2 Hrs.	No SCC or surface effect	
			4-3-1 I	850°F, 2 Hrs.	Fracture (SCC)	
			6-4 I	850°F, 2 Hrs.	Fracture (SCC)	
			8-1-1 I	850°F, 2 Hrs.	Fracture (SCC)	
		U-Bend	8-1-1 I Timet Ht D8141	185°F, 20 Min. Vapor degrease per BAC 5408	No visible SCC or surface effect	
				Now heat 1000°F, 4 Hrs.	No SCC or surface effect	
30.1.21	Water (H_2O)					A
		U-Bend	8-1-1 I Timet Ht D8141	75°F. Time not recorded, distilled water	No SCC or surface effect	

TABLE 4.—COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
			Material Class Solvent			
30.1.21 (cont'd)			6-4	1000°F, 4 Hrs. Distilled water	Slight surface etch	
			8-1-1	1000°F, 4 Hrs. Distilled water	Slight surface etch	
			6-4	1000°F, 4 Hrs. Seattle City water	Slight surface etch to slight SCC	
			8-1-1	1000°F, 4 Hrs. Seattle City water	Slight surface etch to slight SCC	
			Material Class Stabilizer, Machining			
31.1.1	Rigidax Blue F (M. Argüeso & Co., Inc.)	Double U-Bend	6-4 I	1000°F, 3 Hrs.	Slight etch only	A
31.1.2	Rigidax PF (Argüeso)	Double U-Bend	6-4 I	1000°F, 3 Hrs.	SCC, Level 5	X
31.1.3	Rigidax W1 Blue	Double U-Bend	6-4 I	1000°F, 3 Hrs.	Severe etch only	A (?)
31.1.4	Rigidax WI Green	Double U-Bend	6-4 I	1000°F, 3 Hrs.	SCC, Level 5	X
31.1.5	Rigidax W1 NF	Double U-Bend	6-4 I	1000°F, 3 Hrs.	Severe etch only	A (?)
31.1.6	Rigidax YF	Double U-Bend	6-4 I	1000°F, 3 Hrs.	SCC, Level 5	X
31.1.7	Barkerwax 3BE (Barker Enterprises)	Double U-Bend	6-4 I	850°F, 18 Hrs.	No surface effect	A
31.1.8	Cerrolow 140 (Cerrode Pasco Corp.) (12.6 Sn, 47.5 Bi, 25.4 Pb, 9.5 Cd, 5.0 In)	Double U-Bend	6-4 I	170°F, 16 Hrs.	No surface effect	A
		Double U-Bend	6-4 I	450°F, 16 Hrs.	SCC, Level 5	X
		Double U-Bend	6-4 I	1000°F, 16 Hrs.	SCC, Level 5	X
31.1.9	Cerrolow 174 (Cerro de Pasco) (57Bi, 17 Sn, 26 In.)	Double U-Bend	6-4	48 Hrs.	No surface effect	A

TABLE 4.—COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Stabilizer, Machining				
31.1.10	Jarvie 40	Double U-Bend	6-4	650°F, 24 Hrs.	No surface effect	A
	(Jarvie Paint Co.)	Double U-Bend	6-4	1000°F, 15 Hrs.	No surface effect	A
		Material Class Stripper, Paint				
32.1.1	K-58-C	Double U-Bend	6-4	75°F, 48 Hrs.	No surface effect	A
	(Keelite Corp.)	Double U-Bend	6-4	650°F, 65 Hrs.	SCC, Level 2-3	X
		Double U-Bend	6-4	1000°F, 4 Hrs.	SCC, Level 4	X
32.1.2	Del-Chem 19AC	U-Bend	6-4	450°F, 168 Hrs.	No surface effect	A
				550°F, 168 Hrs.	No surface effect	A
				700°F, 24 Hrs.	Stress corrosion	X
		Material Class Tape, Temporary				
33.1.1	350 (3M Corp.)	Single U-Bend	6-4 I	350°F, 168 Hrs.	No surface effect	A
		Single U-Bend	6-4 I	500°F, 168 Hrs.	No surface effect	A
		Single U-Bend	6-4 I	1000°F, 4 Hrs.	No surface effect	A
33.1.2	Y9241 (3M Corp.)	Single U-Bend	6-4 I	350°F, 168 Hrs.	No surface effect	A*
		Single U-Bend	6-4 I	500°F, 168 Hrs.	No surface effect	A*
		Single U-Bend	6-4 I	1000°F, 4 Hrs.	SCC, Level 1-2	X
33.1.3	5863 (Mystic Co.)	Single U-Bend	6-4 I	350°F, 168 Hrs.	No surface effect	A
		Single U-Bend	6-4 I	500°F, 168 Hrs.	No surface effect	A
		Single U-Bend	6-4 I	1000°F, 4 Hrs.	No surface effect	A
33.1.4	6110 (Mystic Co.)	Single U-Bend	6-4 I	250°F, 168 Hrs.	No surface effect	A*
		Single U-Bend	6-4 I	1000°F, 4 Hrs.	SCC, Level 1-2	X
33.1.5	733 (Permacel Co.)	Single U-Bend	6-4 I	350°F, 168 Hrs.	No surface effect	A
		Single U-Bend	6-4 I	500°F, 168 Hrs.	No surface effect	A
		Single U-Bend	6-4 I	1000°F, 4 Hrs.	Slight surface etch, Level 0	A

*Remove completely before subsequent stress-relieving or heat treatment.

TABLE 4.–COMPATIBILITY DATA, MANUFACTURING AID MATERIALS (continued)

Material Number	Material	Test	Alloy	Test Parameters	Results-Observations	Compatibility Rating
		Material Class Tape, Temporary				
33.1.6	HS 8171 PS (Richmond Corp.)	Single U-Bend	6-4 I	350°F, 168 Hrs.	No surface effect	A*
		Single U-Bend	6-4 I	500°F, 168 Hrs.	No surface effect	A*
		Single U-Bend	6-4 I	1000°F, 4 Hrs.	SCC, Level 1-2	X
33.1.7	90W (Tuck Tape Co.)	Single U-Bend	6-4 I	350°F, 168 Hrs.	No surface effect	A
		Single U-Bend	6-4 I	500°F, 168 Hrs.	No surface effect	A
		Single U-Bend	6-4 I	1000°F, 4 Hrs.	Slight surface effect, Level 0	A

*Remove completely before subsequent stress-relieving or heat treatment.

5.4 SODIUM CHLORIDE INDUCED STRESS CORROSION CRACKING OF TITANIUM

The stress corrosion produced in Ti-6Al-4V U-bend specimens by varying low concentrations of chloride ion in distilled water is illustrated by the photomicrographs in figures 5 to 12. Exposures were conducted as described in section 3.3.2. One interesting observation was that stress corrosion cracking was more severe with sodium chloride dissolved in distilled water than with a comparable solution of sodium chloride in tap water.

5.5 METHANOL INDUCED STRESS CORROSION CRACKING OF TITANIUM

Special interest in the compatibility of methyl alcohol with titanium alloys was prompted by the failure of an Apollo fuel tank in October 1966, during pressure testing with methanol. Methanol test data obtained in this program is given in table 4, material code number 30.1.13. This section contains metallographic results on several fractured specimens.

Fractographic examinations were carried out on three specimens: No. 8-270, Ti-8Al-1Mo-1V; No. 8-39, 8Al-1Mo-1V; and No. 6-73, Ti-6Al-4V. Each specimen was a standard U-bend, and immersed in methanol containing 400 ppm of water until failure. One similar specimen, immersed in methanol containing 1300 ppm of water, did not fail in two weeks, but failed within two hours when transferred into methanol of low water content.

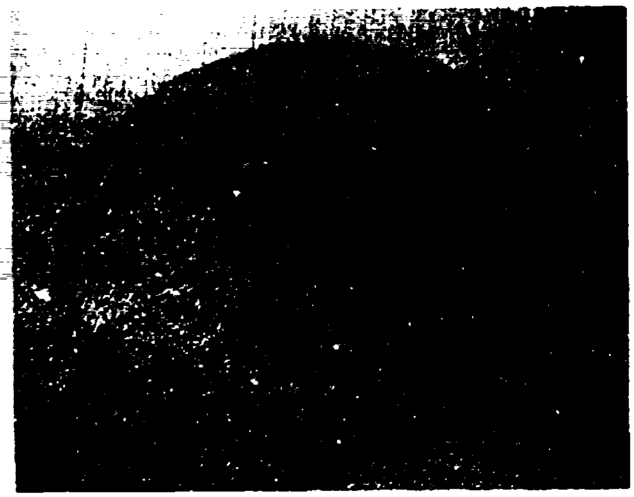
One half of each specimen was cut and mounted for metallographic examination, and the opposite half retained intact for electron microscopic examination. The metallographic profiles of the secondary cracks showed a transgranular crack path (figures 14-20). The Ti-6Al-4V specimen no. 6-73 showed that the beta phase is more ductile than the alpha phase.

Replicas of the origin which represents the slow crack growth region always exhibited mixed cleavage and ductile fracture features. A lesser degree of cleavage was observed in the areas of rapid fracture (see figures 21-23). The difference in fractographic features between the origin (slow growth region) and the areas of rapid fracture was not as profound as expected. The microscopic difference was more outstanding.

Specimen No. 6-73, Ti-6Al-4V did not exhibit any well defined slow growth regions. Representative areas showed mixtures of cleavage and ductile fracture features (figure 23).

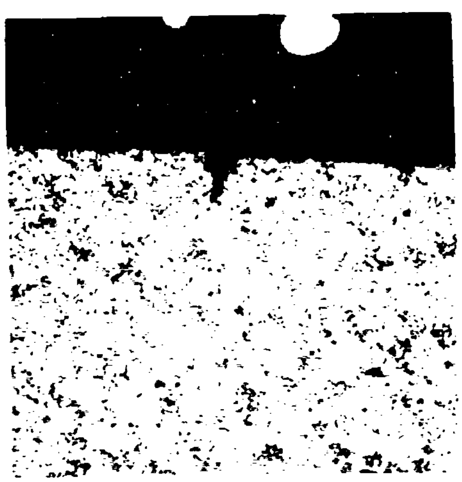
All the specimens that have failed when immersed in methanol, both Ti-6Al-4V and Ti-8A-1Mo-1V, did so in a brittle fashion with cleavage features typical of stress corrosion cracking. The features are similar to those found in specimens that have failed in 3.5 percent salt water environments. The beta or transformed beta regions behave in a ductile manner. Williams (ref. 11) has found both alloys, Ti-6Al-4V and Ti-8A-1Mo-1V, generally exhibit cleavage failure through the primary alpha phase, and ductile features through the beta and transformed beta regions during stress corrosion.

Beck and Blackburn (ref. 12) found that in salt water environments the fracture mode of the alpha phase usually changes from cleavage in the SCC zone to ductile rupture in the rapid fracture zone. This change was not observed in these specimens. The difference is believed to be due, in part, to the difference in specimen size and geometry. Most experimental work has been conducted using heavier gage, notched bend specimens with the crack traveling in the long, transverse direction whereas the subject specimens cracked in the short transverse direction.



16X

FIGURE 5.–HOT-SALT SCC OF TI-6AL-4V (5 PPM CL IN DISTILLED WATER; 1000F, 4 HOURS)



160X

FIGURE 6.–HOT-SALT SCC OF TI-6AL-4V (5 PPM CL IN DISTILLED WATER; 1000F, 4 HOURS) DEPTH OF FRACTURE, 1.8 MILS

16X

FIGURE 7.—HOT-SALT SCC OF TI-6AL-4V (10 PPM CL IN DISTILLED WATER; 1000F, 4 HOURS)

190X

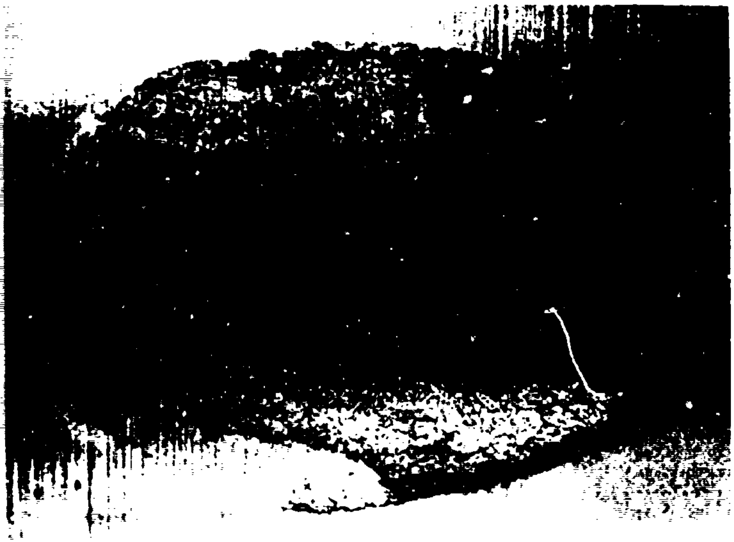
FIGURE 8.—HOT-SALT SCC OF TI-6AL-4V (10 PPM CL IN DISTILLED WATER; 1000F, 4 HOURS) DEPTH OF FRACTURE, 5.2 MILS

16X

FIGURE 9.–HOT-SALT SCC OF TI-6AL-4V (20 PPM CL IN DISTILLED WATER; 1000F, 4 HOURS)

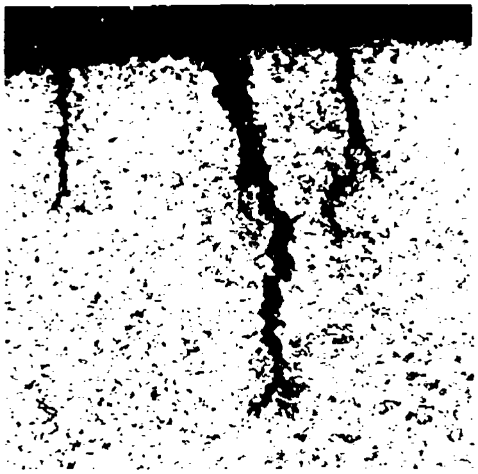
190X

FIGURE 10.–HOT-SALT SCC OF TI-6AL-4V (20 PPM CL IN DISTILLED WATER; 1000F, 4 HOURS) DEPTH OF FRACTURE, 5.6 MILS



16X

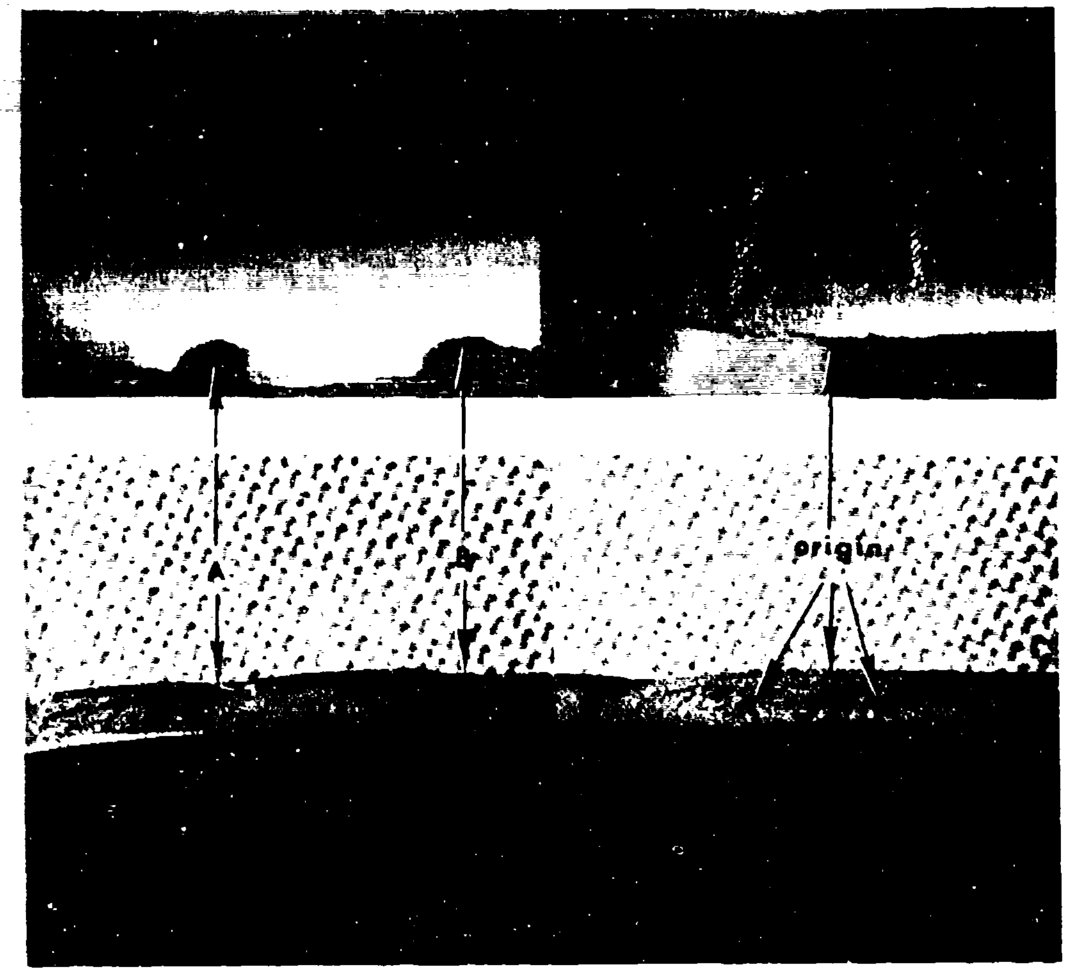
FIGURE 11.—HOT-SALT SCC OF TI-6AL-4V (40 PPM CL IN DISTILLED WATER; 1000F, 4 HOURS)



90X

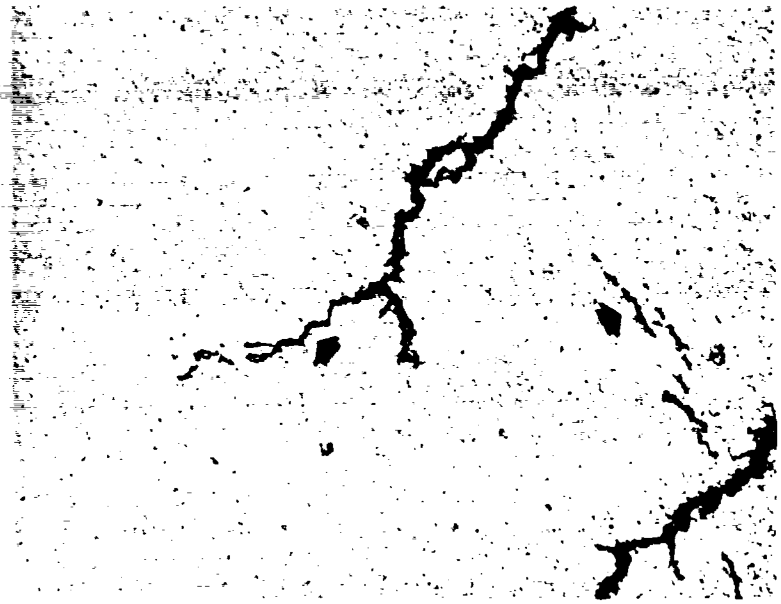
FIGURE 12.—HOT-SALT SCC OF TI-6AL-4V (40 PPM CL IN DISTILLED WATER; 1000F, 4 HOURS) DEPTH OF FRACTURE, 21.3 MILS

Origin and General Surface Topography
Areas A and B are believed to be Secondary Origins



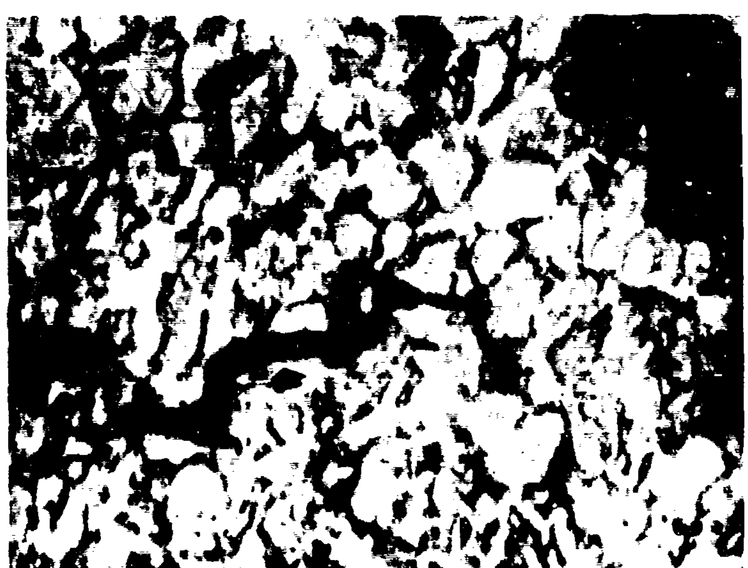
Ti-8Al-1Mo-1V 4X

FIGURE 13.--PROFILE AND FRACTURE SURFACE OF SPECIMEN NO. 8-270



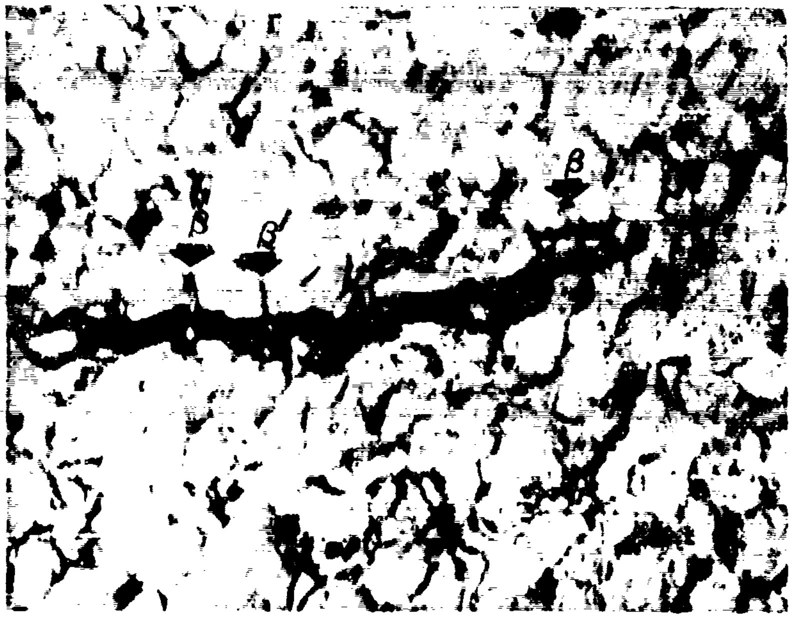
Ti-6Al-4V Kroll's Etch, 200X

FIGURE 14.—SPECIMEN NO. 6-73 SECONDARY CRACK PROFILE (SHOWING A STEP LIKE CRACK PATH WHICH IS TRANSGRANULAR AT HIGHER MAGNIFICATIONS)



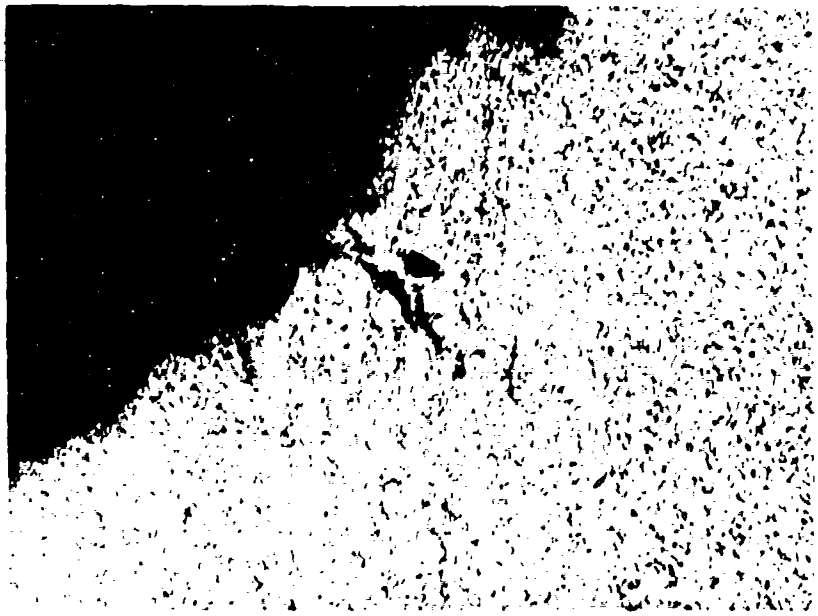
Ti-6Al-4V Kroll's Etch, 2500X

FIGURE 15.—SPECIMEN NO. 6-73 AREA SHOWING THE TRANSGRANULAR NATURE OF THE CRACK PATH



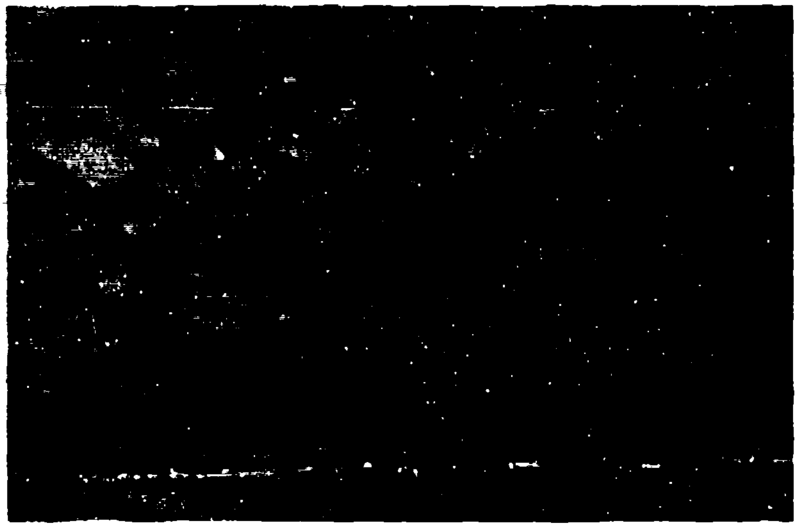
Ti-6Al-4V (2500X)

FIGURE 16.–SPECIMEN NO. 6-73 REPRESENTATIVE AREA SHOWING DUCTILITY OF THE BETA PHASE



Ti-8Al-1Mo-1V Kroll's Etch, 200X

FIGURE 17.--SPECIMEN NO. 8-39 PRIMARY AND SECONDARY CRACK PROFILE SHOWING A CRACK PATH SIMILAR TO Ti-6Al-4V



Ti-8Al-1Mo-1V Kroll's Etch, 2500X

FIGURE 18.–SPECIMEN NO. 8-39 AREA AT A HIGHER MAGNIFICATION SHOWING THE TRANSVERSE CRACK PATH AND SOME ELONGATED PARTICLES

Ti-8Al-1Mo-1V 10,000X

FIGURE 19.–SPECIMEN 8-270 SLOW CRACK GROWTH REGION (ORIGIN) SHOWING A MIXTURE OF PRIMARILY CLEAVAGE AND SOME DUTILE AREAS

Ti-8Al-1Mo-1V 10,000X

FIGURE 20.–SPECIMEN NO. 8-270 SLOW CRACK GROWTH REGION, SIMILAR TO FIG. 19

Ti-8Al-1Mo-1V 10,000X

FIGURE 21.–SPECIMEN NO. 8-270 RAPID CRACK REGION SHOWING MORE DUCTILITY WITH SOME AREAS HAVING CLEAVAGE

Ti-8Al-1Mo-1V 10,000X

FIGURE 22.–SPECIMEN 8-270 RAPID CRACK REGION, SIMILAR TO FIGURE 21

Ti-6Al-4V 10,000X

FIGURE 23.–SPECIMEN NO. 6-73 REPRESENTATIVE AREA ON THE TENSION SIDE SHOWING WELL DEFINED CLEAVAGE FEATURES

6.0 DISCUSSION OF RESULTS

The test results in section 5 are very specific, e.g. the data deals with individual materials tested under particular conditions of temperature and time. This is especially true since most of the materials tested were proprietary products for which chemical composition information was lacking. It is difficult to deduce general statements about compatibility of a class of materials, such as heat treat protective coatings, which are used for a single purpose but may include a variety of chemical compositions. In a sense each material studied constitutes an individual test program, with the test data given in table 4 and the test result summarized in the compatibility rating included therein.

6.1 TEST METHODS

The test methods used to evaluate titanium compatibility changed and evolved during the 1967-1971 time period covered in this document. In the earlier work several test methods were used in studying each material. Later, for reasons discussed below, primary reliance was placed on the U-bend specimen, and work was begun on modifying the method by introducing the double U-bend test for faying surface entrapment simulation, and the indented U-bend test for increased sensitivity.

6.1.1 The Modified Allison Bend Test

This test, as modified, was designed for the detection of the formation of brittle surface layers on exposed specimens. That it is capable of doing so is indicated by data for several scale conditioners (29.1.2-29.1.4, table 4). The 15-25 percent decrease in bend energy of exposed specimens compared to controls is correlated with the formation of a conversion coating. Return of the bend energy to its original value following a short pickling process to remove the surface layer confirms that the bend energy decrease is detecting a surface change.

In a similar fashion this test was capable of detecting surface oxidation produced during very high (1725° and 1900°F) temperature exposures while testing heat treat coatings. (See 27.1.6-27.1.9 and 27.1.28.) However, no significant differences were observed between control and test specimens. This suggests that heat treat coatings produce neither deleterious or protective effects on the titanium.

Reviewing the Allison bend test data led to the conclusion that while the method did detect surface changes, it did not appear to be suitable for studying titanium-material incompatibility. This is especially the case since the specimens were exposed to the test material unstressed, so that the occurrence of stress corrosion cannot be detected.

6.1.2 Emittance Testing

This test was useful for studying the formation of oxide coatings formed on titanium by exposure to high temperatures (1725 and 1900°F) during evaluation of heat treat protective coatings (see 27.1.8, 27.1.9, and 27.1.28). The presence of an oxide coating was indicated by

an increase in the emittance of the surface. A measure of the thickness of the coating was obtained by chemically removing the oxide layer, and measuring the removal required to return to the emittance of the bare metal. As expected this test shows that the oxide film formed in ten minutes at 1900°F is thicker than the film formed in ten minutes at 1725°F. This test can be used to measure the protective ability of heat treat coatings. It was not, however, particularly useful in studying material compatibility.

6.1.3 Chlorine Analysis

Initially it had been planned to rely upon the chlorine content of manufacturing aid materials as a criteria for compatibility, with a maximum of 200 ppm allowed. This was based upon the well-documented occurrence of hot salt stress-corrosion cracking of titanium, and the knowledge that even covalent chlorine compounds will form ionic or ionizable decomposition products at high temperatures.

A number of dye penetrant materials were analyzed for chlorine, but no correlation existed between chlorine content and occurrence of corrosion. In the seven out of thirty-five analyzed materials for which corrosion was observed the chlorine content varied from 5-384 ppm. In the remaining 28 materials which did not produce SCC the chlorine content varied from 51 ppm to 1 percent. In particular, sample 26.3.27 at 700 ppm and samples 26.3.29 and 26.3.30 at 1 percent chlorine passed the corrosion test. This may be because the chlorine was contained in some volatile molecule.

For this reason it is recommended that no arbitrary maximum chlorine content be established, but rather that the chlorine analysis be used as a tool in helping to establish the cause of corrosion, and as a warning to carry out especially careful corrosion testing for materials with high chlorine contents.

6.2 RESIDUE REMOVAL

For many manufacturing aid materials the test temperatures used were extremely severe, well above those encountered during their use in the shop, or subsequently in the airplane. These were employed because of the possibility that titanium parts contaminated by these materials might subsequently be heat treated or stress-relieved at such temperatures. Materials rated X in table 4 may well be usable, if required, in manufacturing if adequate provision is made for removal of residual traces of the material following use.

6.3 DISCUSSIONS OF MATERIAL CLASSES

No general discussion of each class of manufacturing aid materials is possible for reasons previously cited, namely that the classes are grouped by function and not by chemical character, and that the test results are specific for each particular material. General comments about a few classes are given below.

In several cases a much larger number of individual materials within a class were examined than were required to select manufacturing aid materials suitable for the stress-corrosion standpoint. This was done to study the test methods in more detail. One major advantage of

the U-bend test is that the extra expense to include additional materials in a test series is quite low. For example a large number of dye penetrant materials were examined, in part to determine whether production of stress corrosion was correlated with chlorine content.

6.3.1 Machining Lubricants and Coolants

Three members of this class were rated X (incompatible) (21.1.8, 21.1.37 and 21.1.41) based upon the presence of chlorinated solvents in their formulation, even though no evidence of corrosion was observed during testing. However all three of these were tested at an early date before the use of U-bend specimens in the resin kettle test was initiated. In view of the stress corrosion observed for lubricant material 21.1.4, and for several chlorinated solvents in resin kettle tests this seems to be a reasonable, conservative conclusion.

6.3.2 Electrochemical Marking Materials

The X ratings assigned to these materials are almost redundant, since their marking functioning depends upon their ability to attack titanium. Possibly they may safely be used for marking purposes if employed as directed, and carefully removed subsequently.

6.3.3 Penetrant Inspection Fluids

A wide variety of all three subclasses were tested, penetrants, developers, and emulsifier-removers. None of the 41 penetrants tested exhibited incompatibility. This is very reassuring since these are formulated to penetrate into small cracks from whence their complete removal may be difficult. While some developers and emulsifiers produced stress-corrosion it was generally moderate. In any case a large variety of compatible systems were discovered.

6.3.4 Solvents

Test data on the different solvents exhibited a good deal of variability. In part this was attributed to differences in surface preparation; for this reason the nature of the specimens is described in considerable detail in table 4. The data on ethanol, 30.1.7, shows the importance of surface preparation in SCC. The data allows several interesting conclusions.

- The greater stress-corrosion susceptibility of Ti-8A1-1Mo-1V compared to Ti-6A1-4V is shown both for alcohols and for chlorinated compounds.

- Chlorinated solvents (and fluorochlorocarbons) produce stress-corrosion cracking in the resin kettle, U-bend test at high temperatures, where thermal decomposition of the partially confined solvent can occur. It is probable that this effect would not have been noted under test conditions such that the solvent vapors could have diffused away from contact with the specimens.

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

- Compatibility ratings, valid for the test conditions listed in the data tabulation, have been determined for 267 manufacturing-aid materials.
- The simple U-bend test is the most useful method for screening the compatibility of materials with titanium.
- For volatile liquids, the resin kettle modification of the U-bend test is recommended.
- Emittance measurements, combined with controlled chemical etching, can be used to measure the extent of surface oxidation.
- The modified Allison bend test can detect surface changes in titanium, especially the formation of oxide coatings. It is not a useful test for monitoring titanium compatibility of materials.
- Halogenated solvent vapors, restrained in contact with titanium alloys, can produce stress corrosion cracking at 600°F and above.
- The hot extraction method is preferable to the vacuum fusion method for measuring the hydrogen content of titanium.
- The fracture depth produced by 1000°F, 4 hour exposure of titanium U-bend specimens to evaporated trace salt solutions is proportional to the salt concentration of the solutions.
- The chlorine content of manufacturing aid materials is not, per se, a reliable criterion of ability to induce titanium corrosion.
- The fracture mode of the specimens that failed in methanol is typical of transgranular stress corrosion cracking. The alpha phase failed by cleavage and the beta phase by ductile rupture.
- The primary fracture origin and secondary origins of Ti-8A1-1Mo-1V show macroscopically distinguishable zones. Microscopically, the fracture mode of the alpha phase does not change as markedly from the stress corrosion cracking zone to the rapid fracture zone.
- The fracture modes for both the Ti-8A1-1Mo-1V and Ti-6A1-4V are similar to those observed in stress corrosion cracking in saltwater environments.
- As the water content increases in the reagent grade methanol, the susceptibility to stress corrosion cracking decreases.

7.2 RECOMMENDATIONS

- Batch testing of materials using the U-bend specimen is recommended as the primary test for titanium compatibility.
- Chlorine content of manufacturing aid materials should be measured and used as supplemental information in interpreting compatibility test results.
- The compatibility ratings listed in this document should be used with care, taking into account the specific tests used in deriving each rating.
- Special manufacturing methods and controls should be developed to ensure complete removal of any manufacturing aid materials producing SCC at very high temperatures, prior to subsequent heat treat or stress relief operations.

APPENDIX A

METHODS OF CHLORINE ANALYSIS

The following methods of chloride analysis were utilized. The particular method used depended upon the type of material involved and the accuracy required.

1. BOSLER METHOD

This test was used to determine the amount of chlorides in machining lubricants.

Method I. Combustible (Flammable) Lubricants

Five to ten grams of material was burned and the combustion products were aspirated through a 10% NaOH solution. The halides were precipitated with silver and the amount determined gravimetrically.

Method II. Noncombustible Lubricants

A known weight of sample was taken and boiled with 50% nitric acid and silver nitrate. The resultant solution was filtered and washed, then weighed for determination of the amount of chloride.

Both methods were capable of detecting chloride concentrations of greater than 100 ppm.

2. RADIOTRACER SILVER-110

The material to be analyzed is dissolved in a nitric-hydrofluoric acid solution to which a radiotracer of silver-110 is added to precipitate the chloride. The silver chloride is removed by centrifuging and the residual activity counted with scintillation equipment. The procedure will detect 2 mg of chloride.

3. BEILSTEIN TEST

A copper wire is dipped into the candidate solution and the wire placed in a nonluminous gas of alcohol flame. A characteristic green or blue-green color indicates the presence of halide. The test is qualitative.

4. BOMB TEST, PARR

The methods for chloride analysis as described have been successfully used on materials other than penetrants. The method used for actual precipitation of the chloride has varied for some analyses from that described.

Method I. Determination of Chloride in Penetran s

Apparatus

Oxygen Bomb	– Parr or equivalent per ASTM D129-64
Photometer	– Klett-Sommerson or equivalent, or a spectrometer, or a nephelometer
Buret	– 5 ml capacity with 0.01 ml divisions

Reagents

Potassium Hydroxide Solution 3N

Dissolve 168 grams of potassium hydroxide (ACS Reagent Grade) in 1 liter of distilled or deionized water.

Nitric Acid Solution 3N

Dilute 195 ml of concentrated nitric acid (ACS Reagent Grade) to 1 liter with distilled or deionized water.

Silver Nitrate Solution 1%

Dissolve 10 grams of silver nitrate (ACS Reagent Grade) in 1 liter of distilled or deionized water.

Potassium Chloride Solution 100 micrograms per ml

Dissolve 0.2103 grams of potassium chloride (ACS Reagent Grade) in distilled or deionized water in a 1-liter volumetric flask and dilute to mark.

Standardization

Using the 5-ml buret, measure carefully into 10-ml volumetric flasks the following quantities of potassium chloride solution: 0.10, 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.90, and 1.00 ml. To each of these flasks add 2.0 ml 3N potassium hydroxide solution, 3.0 ml 3N nitric acid solution, 1 ml 1% silver nitrate solution and dilute to mark with distilled or deionized water. Invert once and place into a 40°C constant temperature bath for a minimum of 30 min. Remove from the bath and cool rapidly under running cold water. Within an hour of placing the sample into the constant temperature bath, read the absorbance of the sample versus a blank, prepared by adding similar quantities of the reagents to distilled or deionized water in a 10-ml volumetric flask. With the Klett-Sommerson photometer a No. 42 filter was used. For other instruments, the optimum wavelength would have to be determined by a qualitative scan through the visible region for the point of maximum absorbance. This point should give the maximum sensitivity. Plot a curve of absorbance versus concentration. The above solutions contain 10 through 100 micrograms of chloride, respectively.

Procedure

Weigh to the nearest 0.1 mg approximately 0.8 gram of sample into the crucible for the oxygen bomb. Add 2 ml of 3N potassium hydroxide to the bomb, assemble and add the required quantity of oxygen. Ignite and allow to stand for a minimum of 15 min. Disassemble and wash the contents into a 250-ml beaker with distilled or deionized water. Evaporate the contents of the beaker to approximately 20 ml, then filter through a moderately retentive filter, such as S&S 489

white ribbon, into a 100-ml beaker. Wash thoroughly with hot distilled or deionized water. Evaporate the contents of the beaker almost to dryness, or to dryness, but do not allow the residue to bake. Cover the beaker with a watch glass and add 3 ml of 3N nitric acid dropwise, swirling the beaker gently between drops until effervescence ceases. Wash the cover glass and contents of the beaker into a 10-ml volumetric flask with distilled or deionized water and dilute to mark. Pipette 5 ml of the solution into another 10-ml volumetric flask, add 1 ml of silver nitrate, dilute to mark, and place it into a 40 C constant temperature bath for a minimum of 30 min. Remove from the bath and cool rapidly under cold running water. Within an hour of placing the sample into the constant temperature bath, read the absorbence of the solution as compared to a blank prepared by diluting the remaining 5 ml of sample in the other 10-ml volumetric flask to the mark with distilled or deionized water. From the curve prepared under standardization determine the chloride ion concentration in micrograms. The parts per million concentration is then calculated as follows:

$$\text{ppm } Cl^- = \frac{(Cl^- \text{ in micrograms})}{\text{Sample weight in grams}}$$

Method II. Determination of Chloride in Nonoxidizable Materials

Procedure

Weigh a sample of approximately 0.5 gram to the nearest milligram upon a piece of glazed paper. Mix with approximately 2 grams of A.R. sodium carbonate and add to a platinum crucible containing approximately 1 gram of A.R. sodium carbonate. Cover the mixture with another gram of A.R. sodium carbonate and place in a muffle furnace. Let the temperature come up slowly until 850° to 900° C is reached and then allow to fuse for 30 min. Turn off the muffle furnace and allow crucible to cool. Transfer the cold crucible and contents to a 250-ml beaker containing 100 ml of distilled or deionized water to which 5 ml of concentrated nitric acid has been added. Digest upon a hot plate until the fusion mass has been decomposed, then remove the crucible washing thoroughly with hot distilled or deionized water. Filter the solution through a medium retentive filter and wash with hot distilled water into a 250-ml beaker. Evaporate on a hot plate to a volume of approximately 20 ml. If a precipitate forms, refilter and again evaporate. After a clear solution of 20 ml or less is obtained, transfer to a 25-ml volumetric flask and finish the determination by silver chloride turbidity as described in Method I. Adjust the calculation of the silver concentration for the difference in final volumes.

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